Progress Report of the Great Lakes Fisheries Research Branch for 1983

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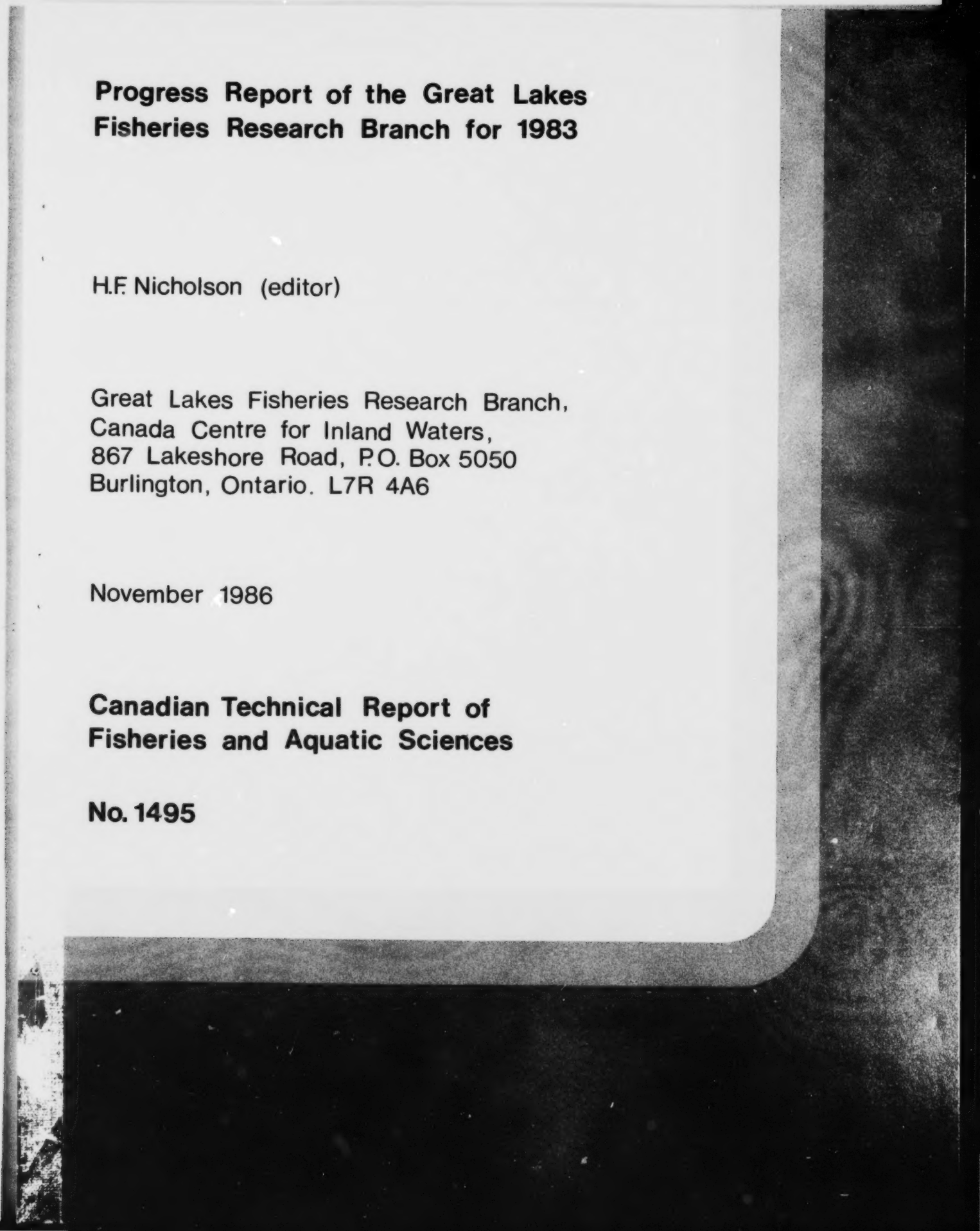

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Canadian Technical Report of Fisheries and Aquatic Sciences

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Les numéros 1 à 456 de cette série ont été publiés à titre de rapports techniques de l'Office des recherches sur les pêcheries du Canada. Les numéros 457 à 714 sont parus à titre de rapports techniques de la Direction générale de la recherche et du développement, Service des pêches et de la mer, ministère de l'Environnement. Les numéros 715 à 924 ont été publiés à titre de rapports techniques du Service des pêches et de la mer, ministère des Pêches et de l'Environnement. Le nom actuel de la série a été établi lors de la parution du numéro 925.

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CANADIAN TECHNICAL REPORT OF FISHERIES

AND AQUATIC SCIENCES 1495

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PREFACE

The Great Lakes Fisheries Research Branch, until recently the Great Lakes Biolimnology Laboratory, is the research wing of the Ontario Region of the Pacific and Freshwater Fisheries of the Department of Fisheries and Oceans.

From its initiation in 1967 as a Detachment of the Freshwater Institute at Winnipeg, it has expanded over the years to an organization of 44 persons with a budget of approximately two million dollars.

The Laboratory's beginnings as a discrete entity in 1973 followed the signing of the Great Lakes Water Quality Agreement by Canada and the United States. The 1978 revision and re-signing of this bilateral agreement resulted in an upgrading of the Laboratory's strength to meet increasing biological concerns in the Great Lakes. This Agreement remains the major mandate of the Branch, though additional responsibilities are incurred under the Fisheries Act.

The GLFRB program is intimately involved with other components of Great Lakes research conducted by a number of federal services of the Department of the Environment, e.g., National Water Research Institute, Ontario Region of the Inland Waters Directorate, Environmental Protection Service, Canadian Wildlife Service, National Health and Welfare, and provincial agencies such as Ontario Ministry of Natural Resources and Ontario Ministry of the Environment. Through further involvement with the International Joint Commission, the Branch has direct dealings with U.S. federal and state agencies involved in Great Lakes research.

During 1980 the Branch initiated a regional research program on the effects of atmospheric loadings of contaminants on lake ecosystems, in particular the effects on fish populations. In 1981 this research became a component of the National Departmental Program on Acid Rain and the Branch has maintained a lead role in the description of effects based on a National Lake Inventory Survey being conducted by the regional groups in the Department.

GLFRB's major programs on the Great Lakes are conducted under three areas defined as Surveillance, Environmental Toxicology, and Ecosystems, with the conduct of the Acid Rain Program under Ecosystems.

PREFACE

La Direction de la recherche des pêches dans les Grands Lacs, qui était jusqu'à tout récemment le Laboratoire de biolimnologie des Grands Lacs, constitue le secteur de la recherche des pêches du Pacifique et en eaux douces de la région de l'Ontario de Pêches et Océans Canada.

Depuis ses débuts en 1967 en tant que détachement de l'Institut des eaux douces à Winnipeg, la Direction de la recherche s'est élargie au cours des années; elle compte maintenant 44 personnes et son budget est d'environ deux millions de dollars.

Les débuts du Laboratoire comme entité distincte en 1973 ont suivi la signature de l'Accord sur la qualité de l'eau des Grands Lacs par le Canada et les Etats-Unis. En 1978, la renégociation de cet accord bilatéral a entraîné une augmentation de l'effectif du Laboratoire, visant à répondre à des préoccupations de plus en plus nombreuses concernant les Grands Lacs. Cet Accord demeure le principal objet du mandat de la Direction, bien que celle-ci assume d'autres responsabilités en vertu de la Loi sur les pêcheries.

Le programme de la DRPGL est étroitement associé à d'autres projets de recherche dans les Grands Lacs réalisés par plusieurs services fédéraux du ministère de l'Environnement, comme l'Institut national de recherche sur les eaux, la région de l'Ontario de la Direction générale des eaux intérieures, le Service de la protection de l'environnement, le Service canadien de la faune, Santé et Bien-être social Canada, et des organismes provinciaux comme les ministères de l'Environnement et des Richesses naturelles de l'Ontario. Grâce à une nouvelle collaboration avec la Commission mixte internationale, la Direction a des rapports directs avec des organismes fédéraux et d'Etat américains participant aux recherches dans les Grands Lacs.

En 1980, la Direction a entrepris un programme de recherches régionales sur les effets des charges atmosphériques en contaminants sur les écosystèmes des lacs, notamment les effets sur les populations de poissons. En 1981, ces recherches sont devenues un élément du Programme ministériel national sur les pluies acides et la Direction a maintenu son rôle principal dans la description des effets, en s'appuyant sur une étude nationale de l'inventaire des espèces des lacs effectuée par les groupes régionaux du Ministère.

Les principaux programmes de la DRPGL sont classés dans trois domaines: la surveillance, la toxicologie environnementale et les écosystèmes. Le Programme sur les pluies acides appartient au secteur des écosystèmes.

ACTING DIRECTOR'S INTRODUCTION

This report represents GLFRB's third effort to produce a somewhat technical document summarizing our research program during 1983. This report is not intended for a general audience, rather it is targetted towards our colleagues in other fisheries and environmental agencies in the Great Lakes basin and elsewhere. The summaries are intended to provide brief overviews of projects with the emphasis on results. We encourage recipients of this report to follow up on the progress of any projects discussed herein with the authors themselves. Reprints of completed studies are available on request. Your comments on what we do are also appreciated.

Progress Reports for 1984 and 1985 are in preparation.

Since 1983 and the publication of this report, the GLFRB Director, Dr. Richard L. Thomas, has left the Department of Fisheries and Oceans to assume the position of Director of the Regional Office of the International Joint Commission in Windsor. We wish him every success.

John M. Cooley

Acting Director

CONTENTS

Surveillance Program

A.1.	Contaminants Surveillance	1
A.2.	Polychlorinated Diphenyl Ethers	2
A.3.	Toxaphene	3
A.4.	Benthic Invertebrates and Polycyclic aromatic Hydrocarbons	5
A.5.	Lake Huron-Georgian Bay Surveillance Field Year, 1980-81	6
B.1.	Fish Tissue Archive	6
B.2.	Extraction Study	7
B.3.	Immediate Field Losses of Chlorinated Hydrocarbon Residues	8
B.4.	Overview	10
C.1.	Fish Health Assessment	12
C.2.	Lake Trout Reproduction	19
C.3.	Plasma Hormone Analysis	21
D.1.	Nannoplankton Dynamics and Phytoplankton Ecology	22
D.2.	Impact of Sediment-bound Contaminants on Biota and Application of Hi-Tech in Toxicity Studies	24
E.1.	Hamilton Harbour Fisheries Rehabilitation	31

Environmental Toxicology Program

A.1.	Methylation and Toxicity of Lead and Tin Compounds in the Aquatic Environment	35
A.2.	Mixed Function Oxidase Activity in Livers of Great Lakes Lake Trout	39
A.3.	Models	43
A.4.	The Toxicity, Accumulation, and Metabolism of Tributyltin Oxide by Rainbow Trout	45
B.1.	Effect of Toxic Materials on Zooplankton and Pelagic Production	46
B.2.	The Effect of Complexation on Metal Toxicity to Zooplankton	48
B.3.	Structure-Activity Relationships in Algal Toxicology	51
B.4.	Quantitative Structure Activity Relationships (QSAR's): the Toxicity of Phenols, Chlorophenols, and Chlorobenzenes to Fish	54
C.1	Ultra-clean Techniques in Assessing Metal Effect on Lake Superior Phytoplankton	57

Fish Habitat Studies

A.1. Turkey Lakes 61
A.2. Mesoscale Studies 62
A.3. National Inventory Survey Analysis 64
A.4. Large-scale Risk Assessment 66
A.5. Effects of Airborne Pollutants on Aquatic Communities of Lake Huron/Georgian Bay 67
B.1. Project Quinte 69
B.2. Larval Fish 71
B.3. TFM Report 72
B.4. Adaptive Environmental Assessment 74
B.5. Pink Salmon Project 74
B.6. Production of Phytoplankton and Invertebrates in South Bay, Lake Huron 75
B.7. Zooplankton and Larval Whitefish: Georgian Bay and Lake Huron 76

SURVEILLANCE PROGRAM

(Program Coordinator: Mr. D.M. Whittle/Dr. H. Shear)

A. CONTAMINANTS IN BIOTA

B. TISSUE ARCHIVE

C. FISH HEALTH STUDIES

D. PHYCOLOGICAL STUDIES

E. HAMILTON HARBOUR REHABILITATION

A. CONTAMINANTS IN BIOTA (Projects Leader: Mr. D.M. Whittle)

A.1. Contaminants Surveillance

Activities during 1983 included the continued monitoring of contaminant burdens, both trace metals and persistent organic compounds, in top predator and forage fish species from several sites on each of the Canadian Great Lakes.

Preliminary evaluation of analytical data indicates that further significant increases in body burdens of PCB have occurred in lake trout from Lake Ontario. Mirex levels have also increased similarly over 1982 levels. The trend of decreasing levels of organic contaminants dating from 1977 was first reversed in 1982 with a sudden increase in PCB levels. Whole fish levels of PCB in age 4+ lake trout from Lake Ontario increased from 3.67 $\mu g\ g^{-1}$ in 1981 to 5.87 $\mu g\ g^{-1}$ in 1982 and subsequently to 6.44 $\mu g\ g^{-1}$ in 1983 samples. Similar increases in organic contaminant levels were not observed in samples of forage species such as rainbow smelt. Further data on

trace metal levels in Lake Ontario fish plus contaminants data on fish samples from the remaining Canadian Great Lakes are currently being evaluated for a report to the IJC Surveillance Workgroup.

Additional contaminants surveillance efforts were directed at determining the environmental significance and Great Lakes distribution of recently identified toxic contaminants such as chlorinated diphenyl ethers, toxaphene, and dibenzodioxins. A limited amount of data was gathered on the levels of PAH's found in benthic invertebrates such as Pontoporeia sp.

A.2. Polychlorinated Diphenyl Ethers (PCDPE)

PCDPE occur as impurities in chlorophenyl preparations and have been estimated at 100 to 1000 ppm in some formulations. Diphenyl ether is used in perfumes, flavourings, industrial solvents and is the major (73.5 percent) component of the heat transfer unit Dowtherm A. PCDPE have been shown to induce liver enzymes and inhibit cytochrome oxidase in rats. Monochloro DPE has a 96-hour LC50 of 0.9 mg l^{-1} for fathead minnows. Bioconcentration factors in trout muscle for monochloro and tetrachloro diphenyl ethers are 736 and 298 respectively which are about five to ten percent of those reported for PCB. PCDPE have been shown to be converted to chlorodibenzofurans by irradiation with UV light and to chlorinated dibenzofurans and dibenzo-p-dioxins by pyrolysis.

Preliminary surveys of fish and sediment samples have identified PCDPE as a trace contaminant throughout Lake Ontario and in the Whitby harbour area in particular.

A monitoring study on 20 fish samples from Lake Ontario and the St. Lawrence River revealed that 17 of the samples contained detectable levels

of PCDPE ranging from 0.2 to 8.2 $\mu g\ g^{-1}$. Further studies are under way to determine the extent of PCDPE contamination in the Great Lakes together with field observations on the extent of food chain transfer of the various isomers of chlorinated diphenyl ether.

A.3. Toxaphene

Studies have continued on the presence of toxaphene residues in Great Lakes fish stocks. As part of the Lake Superior intensive surveillance field year, toxaphene levels were measured in whole fish and edible portion samples of lake trout captured in the Whitefish Bay area near Sault Ste. Marie (Table 1). Whole fish toxaphene concentrations were not correlated to lipid levels ($r = .39$) while there was a significant relationship between edible portion levels and lipid values ($r = .94$). Based on the limited data available, no significant relationship could be developed between whole fish and edible portion toxaphene levels. Further samples from Lake Superior and the other Great Lakes are being analyzed to determine the storage patterns of toxaphene residues in top predator fish species. Joint studies are also under way with the Environmental Toxicology Section to determine the morphological and biochemical effects on fish exposed to various concentrations of toxaphene. Data is being evaluated on backbone structure and chemical composition for samples of rainbow trout exposed for 150 days to toxaphene in combination with various dietary levels of Vitamin C. This information will be compared to similar data from field collections of naturally exposed fish.

TABLE 1. Toxaphene levels in lake trout samples Lake Superior - Whitefish Bay (1983).

Whole Fish	N	X	S.E.	Range
Toxaphene[(1)]	12	2.16	0.32	(1.17- 4.83)
% Lipid	12	20.24	5.84	(14.6 -34.9)
Fillet				
Toxaphene	12	1.27	0.18	(0.53- 2.64)
% Lipid	12	11.89	3.43	(7.0 -25.1)

(1) Results expressed as $\mu g\ g^{-1}$ wet weight unless otherwise noted.

TABLE 2. Location and types of samples collected at each of the offshore sites in Lake Huron - 1980.

Site	Location	Top Predator	Smelt	Sculpin	Benthos	Mysis	Plankton
FRENCH RIVER	45° 55' N 80° 50' W	Walleye	X	X		X	X
SOUTH BAY MOUTH	45° 30' N 82° 00' W	-			x	x	x
BURNT ISLAND	45° 45' N 82° 55' W	Lake Trout	X	X	X	X	X
CAPE RICH	44° 42' N 80° 35' W	Splake	X			X	X
GODERICH	43° 45' N 81° 55' W	-	X		X	X	X
POINT[1] EDWARD	43° 05' N 82° 22' W	Lake Trout					

(1) 1981 Collection

TABLE 3. Trace metal and organic contaminant levels in rainbow smelt (whole fish) from the open waters of Lake Huron and Georgian Bay.*

	Goderich	Cape Rich	Burnt Island	French River
N**	11	12	12	12
Total Length (cm)	17.08 (0.64)	15.33 (0.77)	15.34 (0.51)	15.59 (0.28)
% Lipid	4.46 (0.35)	3.07 (0.17)	4.31 (0.26)	2.99 (0.07)
p,p'-DDE	0.07 (0.01)	0.05 (0.01)	0.07 (0.02)	0.04 (0.00)
DDT	0.11 (0.02)	0.06 (0.01)	0.07 (0.02)	0.07 (0.01)
PCB	0.21 (0.01)	<0.10	0.16 (0.03)	<0.10
Hg	-	0.09 (0.02)	0.05 (0.01)	0.06 (0.00)
Ni	-	0.05 (0.01)	<0.03	0.11 (0.02)
Cu	-	0.97 (0.09)	0.62 (0.06)	0.44 (0.02)
As	-	0.22 (0.01)	0.35 (0.02)	0.23 (0.01)
Se	-	0.70 (0.02)	0.60 (0.01)	0.77 (0.02)

* All results reported as $\mu g\ g^{-1}$ ($\bar{X} \pm$S.E.) unless otherwise noted.
** Each sample consists of a composite of 5 fish.

A.4. Benthic Invertebrates and Polycyclic Aromatic Hydrocarbons (PAH's)

Studies on the role that benthic invertebrates play in the cycling of PAH's in the Great Lakes ecosystem were initiated in 1983. Samples of Pontoporeia, a major dietary item of lake trout, were collected at sites in Lakes Ontario, Huron, and Superior. Preliminary data indicates that chrysene, pyrene, benz(a)anthrene, and benz(a)pyrene were the most predominant compounds found in Lake Ontario samples. Chrysene was the only compound found in Pontoporeia from the Upper Lakes. Further studies will involve the monitoring of zooplankton samples and forage fish species such as sculpins.

A.5. Lake Huron - Georgian Bay Surveillance Field Year, 1980-81 (n)

In conjunction with the Lake Huron intensive surveillance field year (1980-81), a summary report was prepared on the contaminant levels in aquatic biota. Samples of top predator and forage fish species, zooplankton, benthic invertebrates, and net plankton were collected from six sites on Lake Huron - Georgian Bay and analyzed for a variety of persistent organic contaminants and trace metals (Table 2).

Smelt, representing forage fish species, had slightly higher concentrations of PCB at main lake sites when compared to Georgian Bay samples (Table 3). Other contaminants measured in smelt samples displayed minor regional variations in concentrations. Lake trout from southern Lake Huron had the highest mean concentrations of organochlorine residues and lipids of all top predator fish species monitored. PCB and DDT levels were more than twofold greater than mean concentrations found in other lake trout samples (Table 4). A significant food chain biomagnification was calculated for organic contaminants such as PCB and DDT. Trace metal levels did not show significant food chain accumulation. Biomagnification factors for the salmonid food chain ranged from a maximum of 1000 for PCB to increases of only twofold for metals such as As and Se.

B. TISSUE ARCHIVE (Projects Leader: Mr. W.H. Hyatt)

B.1. Fish Tissue Archive

A two-year study indicated that storage temperatures of -20°C and -40°C are not adequate to maintain the integrity of chlorinated hydrocarbon residues in coho salmon whole fish homogenates.

B.2. Extraction Study

This study compared the efficiencies of three extraction methods, involving HCl/methylene chloride, acetone/hexane or acetonitrile, on whole fish and fillet tissue samples dosed with radiolabelled PCB. Data from these extraction methods was compared to levels obtained using a Biological Material Oxidizer (BMO). The BMO gave consistently high recoveries of labelled PCB.

TABLE 4. Trace metal and organic contaminant concentrations in top predator fish species (whole fish) from the open waters of Lake Huron and Georgian Bay.*

	Pt. Edward (Lake Trout)	Cape Rich (Splake)	Burnt Island (Lake Trout)	French River (Walleye)
N	48	50	47	50
% Lipid	18.00 (0.49)	10.35 (0.58)	10.33 (0.63)	8.55 (0.40)
p,p'-DDE	0.60 (0.03)	0.22 (0.01)	0.34 (0.03)	0.12 (0.03)
DDT	1.06 (0.05)	0.25 (0.01)	0.49 (0.04)	0.17 (0.03)
PCB	2.35 (0.14)	0.42 (0.03)	0.92 (0.08)	0.23 (0.05)
Hg	-	0.18 (0.01)	0.14 (0.01)	0.20 (0.02)
Cu	-	0.85 (0.04)	0.99 (0.04)	0.45 (0.01)
Ni	-	0.06 (0.02)	-	0.13 (0.01)
Zn	-	11.61 (0.29)	12.05 (0.23)	12.52 (0.40)
Cd	-	<0.02	0.02 (0.00)	0.02 (0.00)
Cr	-	-	0.12 (0.01)	0.19 (0.01)
As	-	0.18 (0.01)	0.27 (0.02)	0.25 (0.01)
Se	-	0.75 (0.01)	0.81 (0.01)	0.74 (0.02)

*All results reported as $\mu g\ g^{-1}$ Wet Weight ($\bar{X} \pm S.E.$) unless otherwise noted.

There were no significant differences in PCB levels between BMO analyzed samples within each dosage group (1.0 mg kg^{-1} or 0.1 mg kg^{-1} ^{14}C-PCB), regardless of storage temperature (-20°C, -40°C, or -196°C) or storage time (7, 11, 95, and 146 weeks). Extraction methods were compared initially (T0), and after 95 (T4) and 146 (T5) weeks of storage (Fig. 1). High dose samples stored at -20°C or -40°C had significantly lower ($p < 0.05$) ^{14}C-PCB levels than the corresponding BMO levels, regardless of extraction method. Samples stored at -196°C and extracted after 146 weeks with HCl/methylene chloride or acetone/hexane were not significantly different from the corresponding BMO level, but the levels were significantly different from the initial BMO levels. Low dose samples exhibited some erratic behaviour which may indicate a need for higher doses of ^{14}C-PCB in extraction studies such as this.

A companion study demonstrated a significant loss of ^{14}C-PCB in fillet samples after a storage period of 146 weeks at -20°C. These samples were analyzed using the BMO method.

B.3. Immediate Field Losses of Chlorinated Hydrocarbon Residues

Mysis relicta (opposum shrimp) were used in these studies. Samples were frozen on collection day or the following day (processing day). Samples analyzed on the day after collection exhibited losses of heptachlor epoxide, dieldrin, p,p'DDE, o,p'DDT, p,p'DDD, p,p'DDT, gamma chlordane, oxychlordane, mirex, photomirex, PCB and lipid. These losses, although not necessarily significant, occurred for all storage conditions (-196°C, -80°C, and -196°C or -80°C for 24 hours followed by storage at -80°C or -196°C). Residues that had lower levels when stored at -196°C compared to storage at -80°C, on collection

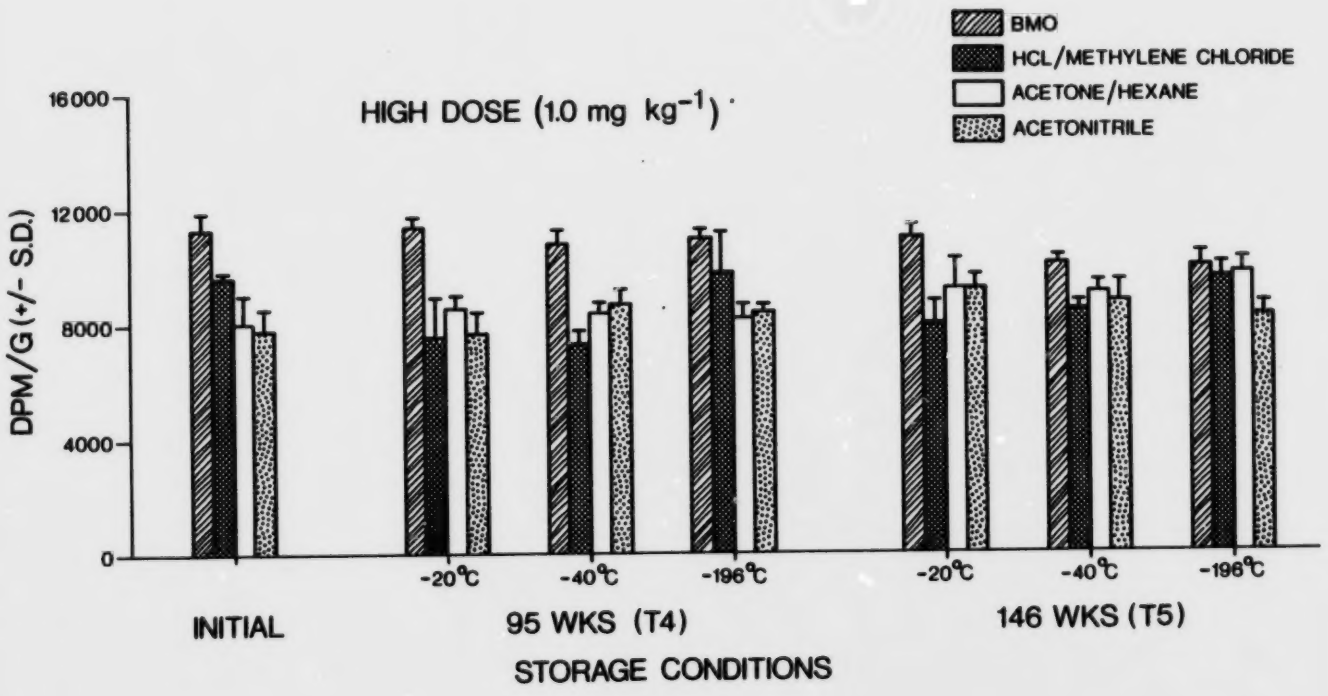


Figure 1. The efficiencies of four extraction methods using radio-labelled PCB.

day, were; HCB, heptachlor epoxide, dieldrin, p,p'DDT, gamma chlordane, and oxychlordane. Another study, utilizing Mysis under the same storage conditions, analyzed lipid content only. Losses overnight ranged from 54 to 62 percent (Fig. 2). A second set of samples will be analyzed in 1984. Other Mysis lipid studies indicated significant losses occurred overnight, regardless of whether samples were fresh or frozen (-196°C or -80°C).

Studies were initiated to investigate methods of overnight sample storage. One method, a common practice in earlier studies, involved placing the bulk Mysis samples on screens immersed in lake water. Samples were kept in the dark at 4°C. The second method, presently used, involves holding the bulk Mysis samples on screens above ice. These jars are kept in the dark at 4°C. All samples held overnight immersed in water had significantly lower ($p < 0.05$) lipid levels than samples held above ice. These lipid levels were significantly lower than the levels found in fresh (collection day) samples.

B.4. Overview

More studies should be completed regarding the archiving of fish samples. Some areas to be addressed may be freezing at lower temperatures, or storing the tissue as solvent extracts or acid extracts.

The recovery rates demonstrated in the BMO study indicated that radiolabelled PCB was not lost, and therefore PCB may merely become less extractable over time. This would lead to an inaccurate assumption that PCB was lost.

Levels of chlorinated hydrocarbon residues and lipids were lost from the fragile Mysis relicta when the samples were not processed immediately.

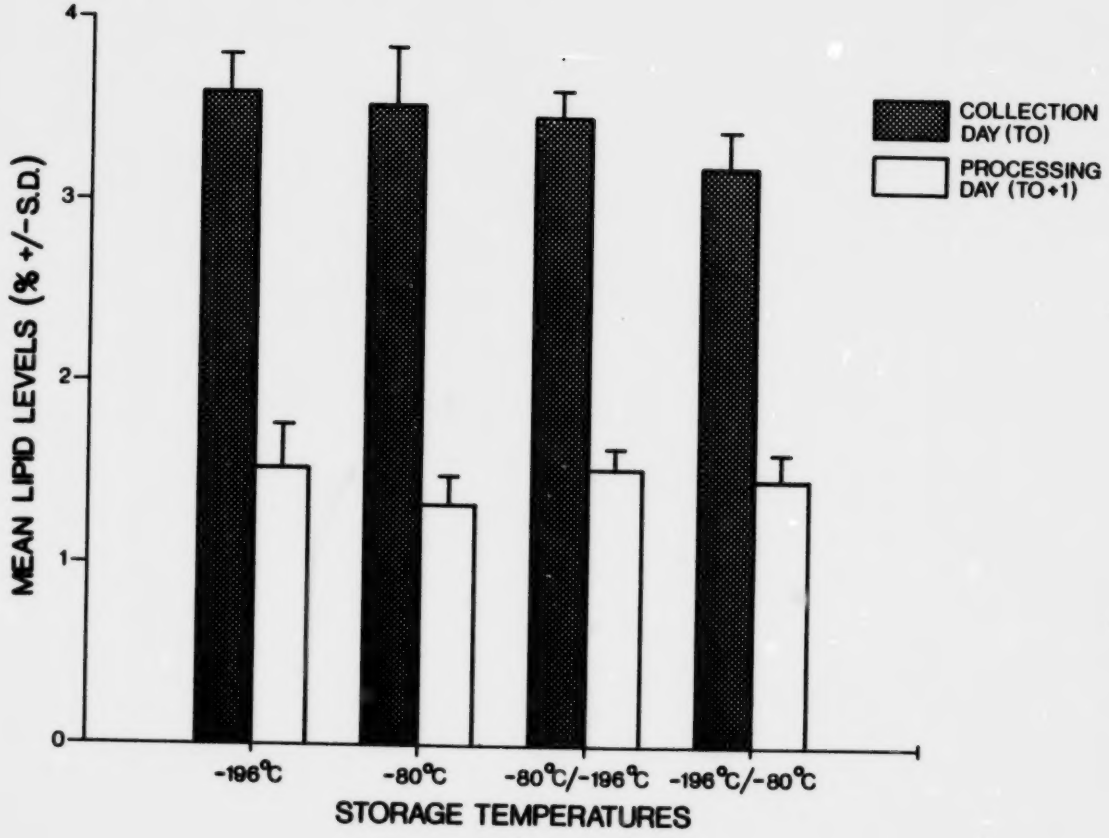


Figure 2. Lipid levels in Mysis stored on collection day or processing day.

Further losses occurred, dependent on the temporary storage conditions used. Samples such as Mysis should be processed as soon as possible to obtain levels representative of environmental conditions. This may not always be possible, but the fact that contaminant losses may have already occurred in the field should be considered. Freezing at -80°C on collection day seems to be the best method for obtaining accurate chlorinated hydrocarbon residue levels in Mysis. This method is recommended upon consideration of the residue levels obtained, the ease of sample storage in the field after collection and the cost and convenience of long-term storage.

C. FISH HEALTH STUDIES (Projects Leaders: Mr. V. Cairns/Mr. J.D. Fitzsimons)

C.1. Fish Health Assessment

The white sucker spawning population in Grindstone Creek (Hamilton Harbour) was monitored for the third and final year in 1983. Only ten percent of the tagged fish from the 1982 run were recovered out of a total of 1,500 fish captured (and tagged) in 1983. The purposes of this project were threefold: 1) to determine if fish from a highly contaminated area such as Hamilton Harbour showed evidence of population stress (abnormal growth, missing year classes, or increased mortality rates); 2) to determine if the frequency of occurrence of lip papillomas was consistent with results observed in the 1981 and 1982 spawning runs; and, 3) to observe changes in tumor development in individuals over a three-year period.

Overall, the results supported the previous data indicating a normal distribution of year classes within the population. There were no differences in growth between papillomatous and normal fish (Fig. 3). None of the

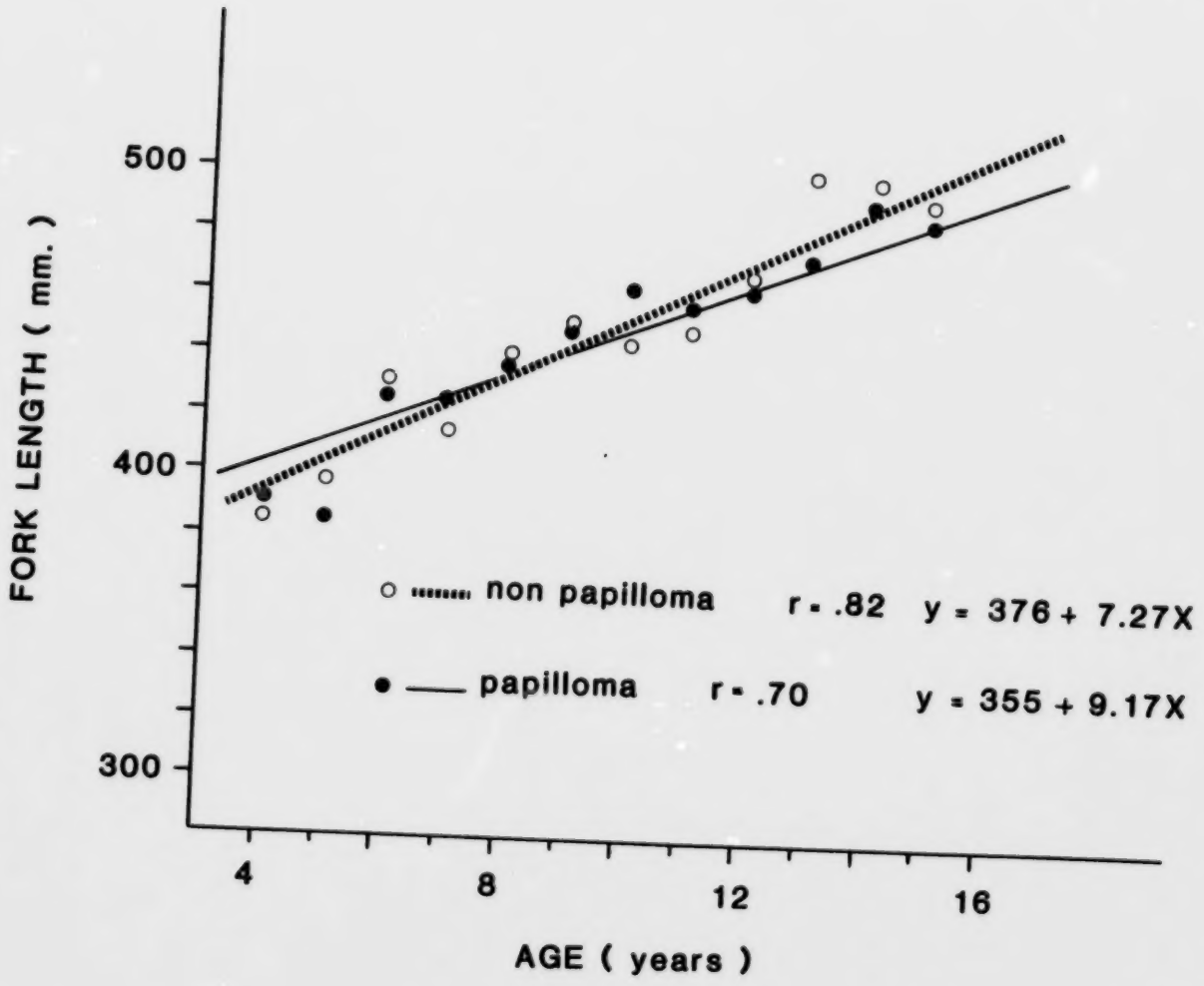


Figure 3. The growth of papillomatous and non-papillomatous white suckers from Grindstone Creek.

recaptured fish had lost papillomas which were observed in previous years and many of the fish which had papillomas in 1981 and 1982 had increased the size of the original tumor and in most cases had also increased the number of tumors. The ten percent recapture rate is surprisingly low and may be due to tagging mortality, escape from the fish weir, or straying into other spawning streams. We attempted to investigate the cause and found that a small number of tagged fish held in the laboratory for six months developed extensive muscle necrosis in the area of the anchor tag. However, it is very unlikely that this is responsible for the low returns of tagged suckers to Grindstone Creek. Fishermen in Grindstone Creek returned an additional 25 tags from fish captured upstream of the weir indicating that the low tag returns were due, in part, to fish by-passing the weir during flood conditions. This is not surprising since increasing water level is a major factor controlling the upstream migratory behaviour of these fish. There were no tags returned by fishermen from any other streams in the area and no tagged fish were found during an extensive electrofishing survey in Six Mile, Spencer, Bronte, or Forty Mile Creeks.

Histological analyses of the various organ systems in Hamilton Harbour white suckers show that these fish are affected by more than epidermal papillomas (Table 5). The significance of these lesions to individual survival has not yet been determined.

In addition to monitoring the spring-spawning run, an extensive survey of papilloma frequency was conducted in Lakes Ontario and Huron. The results of this survey are reported in Figures 4 and 5.

Efforts were made throughout 1983 to monitor the movements of white suckers from Hamilton Harbour. Gill nets were fished once per month from June

TABLE 5. Lesions found in Hamilton Harbour white suckers.

ORGAN/TISSUE	LESION
1. Gill	lamelar fusion, edema, hyperplasia, aneurysms, diffuse necrosis
2. Lip and head	epidermal papilloma, lipoma, chondroma
3. Skin (epidermis + dermis)	epidermal papilloma, hyperplasia, dermal fibroma, dermal fibrosarcoma, squamous cell carcinoma
4. Thyroid	no significant lesions
5. Heart	hyaline-like degeneration, excessive pericardial fat, focal endocarditis, parasites (metazoan larvae)
6. Liver	vacuolated hepatocytes, hepatitis, peribiliary fibroplasia, zonal necrosis, hepatocellular carcinoma
7. Spleen	vascular congestion
8. Kidney	congestion, granuloma
9. Gonad	spermatic seminoma, lipoma
10. Skeleton	spinal fusion, scoliosis, lordosis

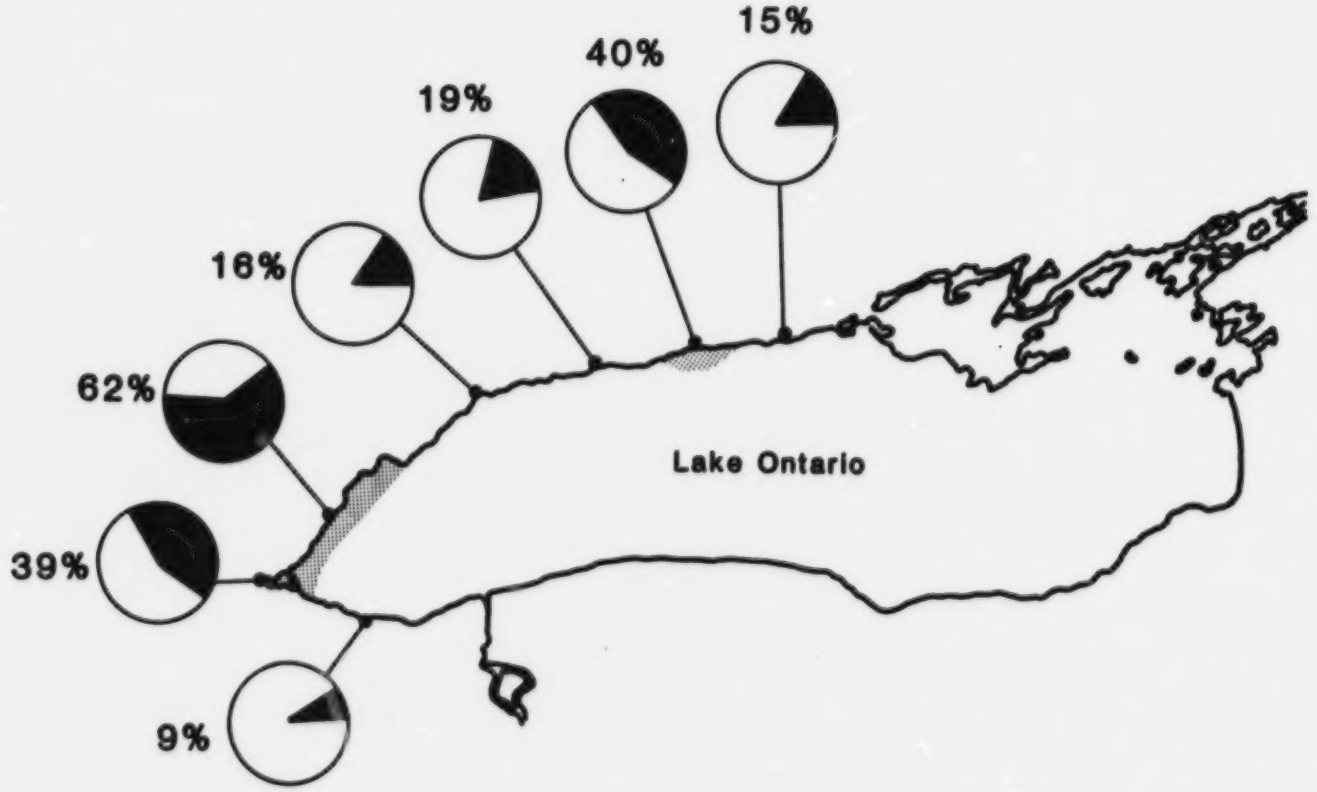


Figure 4. Papilloma prevalence in white suckers greater than 40 cm fork length.

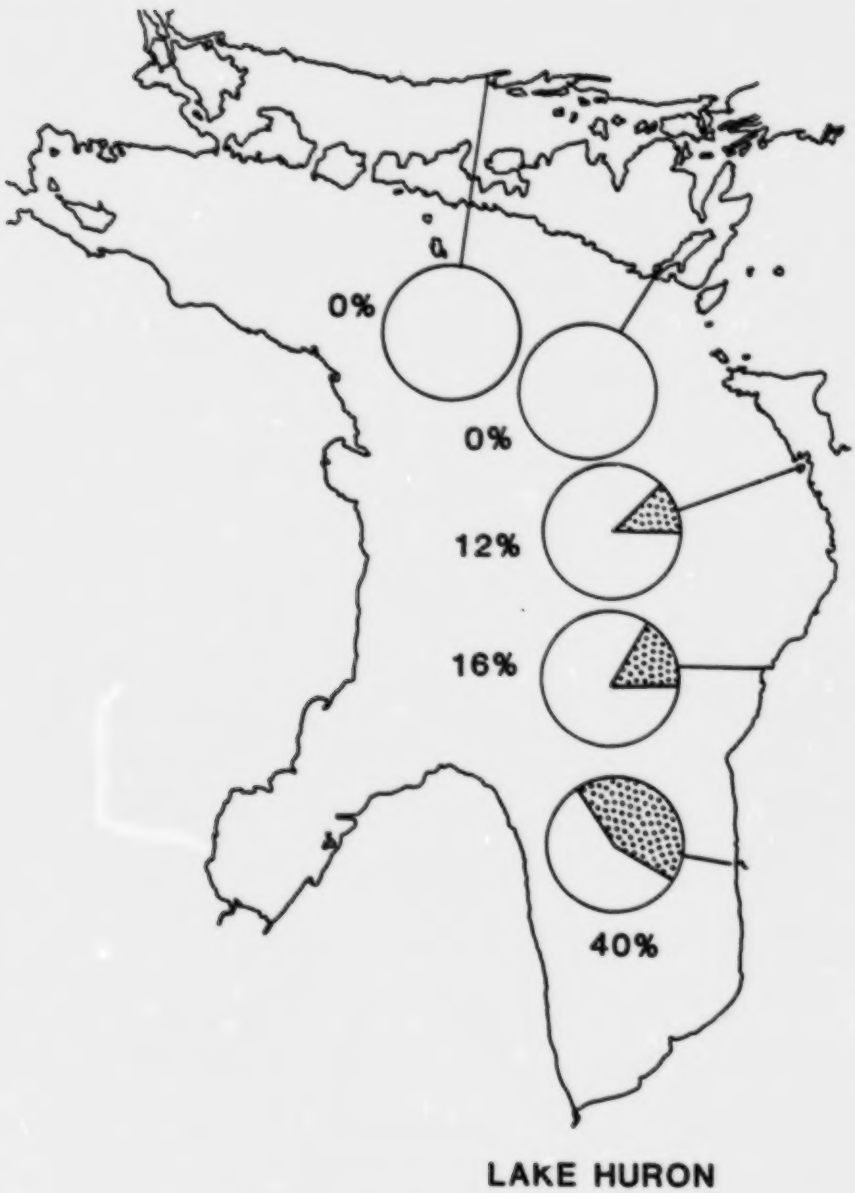


Figure 5. Papilloma prevalence in white suckers greater than 40 cm fork length.

through December at ten sites between Hamilton Harbour and the Niagara River. Tag returns indicate that white suckers leave the harbour in June and July when the water temperature increases, and move into Lake Ontario. One white sucker was recaptured near St. Catharines more than 40 km from the spawning site. However, the majority of tagged fish were captured along the southwest shore of Lake Ontario within ten km of Hamilton harbour. The larger white suckers move into the harbour in October and November, and by December tagged fish were captured at the mouth of Grindstone Creek where they were tagged during the spawning migration in April of the previous year. These data suggest that white suckers in the Grindstone Creek spawning run are exposed to the Hamilton Harbour environment from October through June.

Hamilton Harbour sediments contain elevated levels of copper, zinc, cadmium, lead, and nickel. Some of these metals are known to cause compression, asymmetry, fusion, and dislocation of spinal vertebrae in fish. A preliminary survey was conducted to determine if these anomalies were occurring in fish from Hamilton Harbour. The results are presented in Table 6. Although only a few animals of each species were examined, the fish showed some evidence of compression and fusion of vertebrae, suggesting that a more extensive survey be undertaken in 1984.

C.2. Lake Trout Reproduction

Additional prevalence data was collected in 1983 describing the occurrence of gonadal constrictions in Lake Ontario and Lake Erie lake trout, and in brook trout, rainbow trout and splake (Table 7). Constrictions were found in each species including hatchery fish, providing further evidence that this anomaly is not confined to lake trout or to the Great Lakes.

Developing eggs can be exposed to contaminants through transfer of contaminated lipids from the female to the egg and by direct exposure to trace amounts of chemicals in the environment. A study was initiated to compare the effects of parental transfer and ambient exposure to contaminants on egg development. Lake Ontario lake trout eggs from eight-year-old females and sperm from normal males were collected from the eastern end of Lake Ontario,

TABLE 6. Spinal anomalies in Hamilton Harbour fish.

Species	No. observed	No. with anomalies	Anomaly
Pumpkinseed sunfish	12	0	-
Black crappies	7	0	-
Carp	17	0	-
Goldfish	3	0	-
Rock bass	5	1	Compression
White sucker	19	2	Fusion
Gizzard shad	10	1	Fusion
Brown bullhead	67	4	Fusion

TABLE 7. Prevalence of testicular constrictions.

Species	Location	Age	Sample Size	Condition	Prevalence (%)
Brook trout	Hatchery (Maple)	-	63	partly spent	25.4
			93	resorbing	5.4
Splake	L. Huron	-	322	mature	32.0
Rainbow trout	L. Ontario	-	129	ripe	14
Lake trout	L. Erie	3	12	mature	8.3
		4	21	mature	4.8
		5	4	mature	25.0
	L. Ontario	4	74	mature	39.2
		5	40	mature	37.5
		6	47	mature	34.0
		7	11	mature	18.2
		8	7	mature	14.3
		9	4	mature	50.0

courtesy of the New York Department of Environmental Conservation. Each fertilized group of eggs was separated into three lots. One lot of eggs was placed in astroturf egg containers and incubated in Lake Ontario at 10 m depth. The second and third lots were incubated in the laboratory at 9°C and at ambient temperature (2° to 9°C) respectively. The experiment was duplicated with control eggs from eight-year-old Lake Manitou fish, kindly provided by the Ontario Ministry of Natural Resources. Although there was no difference in percent fertilization between eggs from Lake Ontario (75 percent) and Lake Manitou (83 percent), there was greater mortality in the Lake Ontario eggs at all developmental stages and at 9°C (Table 8). In addition, the eggs and fry from Lake Manitou were significantly larger than those from Lake Ontario. Yolk sac conversion efficiency of Lake Manitou sac fry was significantly higher and was associated with a significantly greater percentage of yolk at swim up. In addition, the heart rate (one measure of

metabolic activity) of Lake Ontario embryos was significantly slower (64 beats per minute) than the heart rate of Lake Manitou embryos (121 beats per minute).

TABLE 8. Comparison of mortality rates of developing lake trout eggs from Lake Manitou and Lake Ontario at 9°C and ambient temperatures.

Lake	Temperature	Mortality (%)		
		Hatch	Yolk Sac Fry	Edematous Fry
Manitou	ambient	1.3	0.9	2.9
	9° C	3.1	2.0	1.6
Ontario	ambient	12.6	2.9	1.1
	9° C	21.1	10.9	12.6

The effects of these observations on natural reproduction are unknown. There is no information describing the effects of depleted or excessive yolk at swim up. Presumably, fish with depleted yolk reserves must begin feeding earlier than fish with large yolk deposits. Similarly, reduced size at hatch would adversely affect survival potential. This study has shown that Lake Ontario lake trout have higher mortality rates, depleted yolk reserves, and lower heart rates than Lake Manitou fish, indicating metabolic/nutritional differences between these stocks and further suggesting that the Lake Ontario fish may not be in optimum condition at hatch.

C.3. Plasma Hormone Analysis

The 1982 analyses of plasma hormones by H. Freeman and G. Sangalang (Department of Fisheries & Oceans, Halifax) indicated that testosterone levels were significantly lower in constricted than in non-constricted lake trout.

These results were based on a small number of fish and it was necessary to collect and analyze additional samples.

Freeman and Sangalang kindly provided the training necessary to allow GLFRB to perform the TLC method of hormone analyses. There were many problems transferring the method, but a reproducable analytical procedure was finally established in late 1983. The analyses of seasonal changes in lake trout androgens will be completed in 1984.

D. PHYCOLOGICAL AND BIOASSESSMENT STUDIES (Projects Leader: Dr. M. Munawar)

D.1. Nannoplankton Dynamics and Phytoplankton Ecology

(a) Significance of autotrophic picoplankton in the Great Lakes

Research dealing with the size fractionation of phytoplankton biomass and its community metabolism has been conducted on the Great Lakes in this laboratory since 1972. The results have demonstrated the abundance and importance of nannoplankton and ultraplankton. However, in the light of recent awareness about smaller size organisms in marine environments, our focus of attention was concentrated on <5 um size assemblage and, more recently, picoplankton (<3 um, <2 um, and <1.2 um size fractions). Considerable effort was put into developing a differential filtration procedure and for the concentration of picoplankton for enumeration by light and epifluorescence microscopy.

Chlorophyll *a* extractions were conducted along with experiments to determine carbon-14 uptakes. Earlier picoplankton studies (<3 um) carried out at an offshore station of Lake Superior indicated that picoplankton contribute on an average 42 and 47 percent to the total chlorophyll *a* and primary

production respectively. Studies carried out in 1983 showed that the picoplankton (<2 um) contributed from 6 to 35 percent to the total chlorophyll a in Lake Erie, and 4 to 41 percent of the total chlorophyll a in Lake Superior during a spring cruise. In terms of primary production, picoplankton (<2 um) contributed 14 to 26 percent and 6 to 19 percent in Lakes Erie and Superior respectively for the same spring cruise. Our results report the importance of picoplankton in the Great Lakes productivity for the first time.

(b) Deep phytoplankton maxima

Deep phytoplankton maxima have attracted the attention of limnologists recently since they could play a very important role in the overall lake dynamics. Work was carried out in Lakes Ontario and Superior to study their presence, composition, and physiological status. The maxima were usually composed of viable organisms of algal origin as opposed to detritus or senescent nature, as believed by some researchers. These organisms were found to be sensitive to contaminants.

(c) Lake Superior ultraplankton dynamics

Lake Superior was the focus of the 1983 intensive surveillance program. Besides spatial coverage of algal abundances, several experiments with the ultraplankton of Lake Superior were done in order to follow up our earlier research. Experiments dealt with nutrient and contaminant additions under varying light conditions. A newly-designed incubator was used to simulate light regime of deep strata. The results provided interesting information concerning the ecological niche of these small-sized organisms, which are

overwhelmingly dominant in Lake Superior. For example, the data indicated that Lake Superior algae were able to adapt rapidly to changing light regimes and photosynthetic inhibition, due to high light intensities, was not evident during short term exposures. A part of the Lake Superior work will be the basis of a report to the IJC Lake Superior Task Force.

(d) Sensitivity of ultraplankton and picoplankton to contaminants

Various size assemblages of natural phytoplankton from stations across the Great Lakes were used to determine the toxicity of a mixture of heavy metals. Carbon-14 fractionation bioassays were conducted in an incubator to determine the differential responses of phytoplankton fractions (>64, 20-46, 10-20, and <10 um). The lowest metal mixture concentration (50 percent lower than the concentration recommended in the Great Lakes Water Quality Objectives as safe for biota) consistently inhibited the ultraplankton (<10 μm) by 55 to 95 percent in Lake Superior (Fig. 6). Similarly, picoplankton (<1.2 μm) bioassay results showed significant inhibition of carbon-14 uptake by 68 to 96 percent in Lake Ontario (Fig. 7). It is apparent that the recommended safe levels are not safe for ultraplankton and picoplankton which provide a major portion of the zooplankton's food ration. It was shown that Algal Fractionation Bioassays (AFB's) have great potential as a monitoring tool for the bioassessment of effluents, dredge spoils, and other toxic substances, since the method is sensitive, rapid, and inexpensive.

D.2. Impact of Sediment-bound Contaminants on Biota and Application of Hi-Tech in Toxicity Studies.

In order to recommend suitable and sensitive procedures for routine assessment of the impact of sediment-associated contaminants on Great Lakes biota,

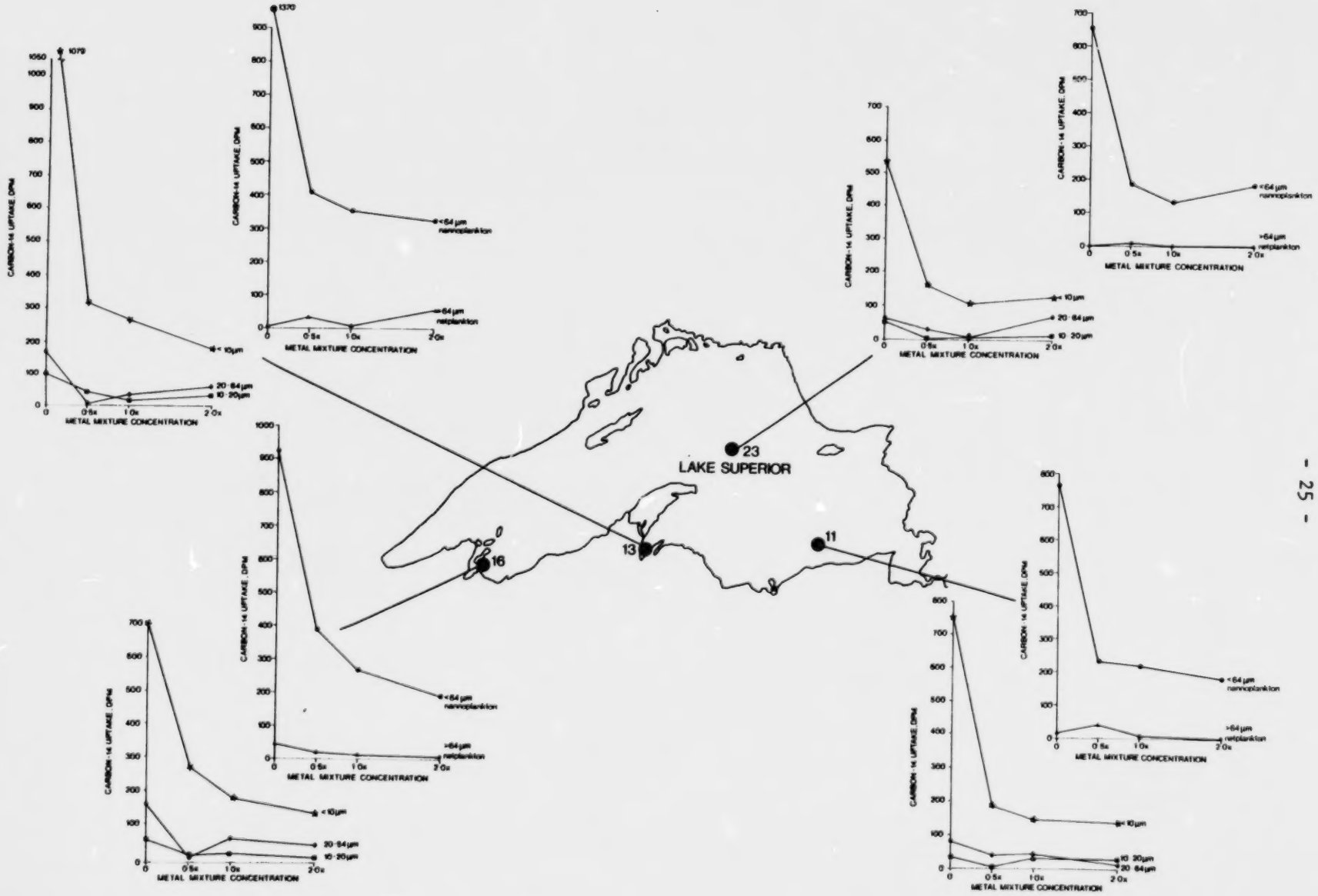


Figure 6. Algal fractionation bioassays in Lake Superior.

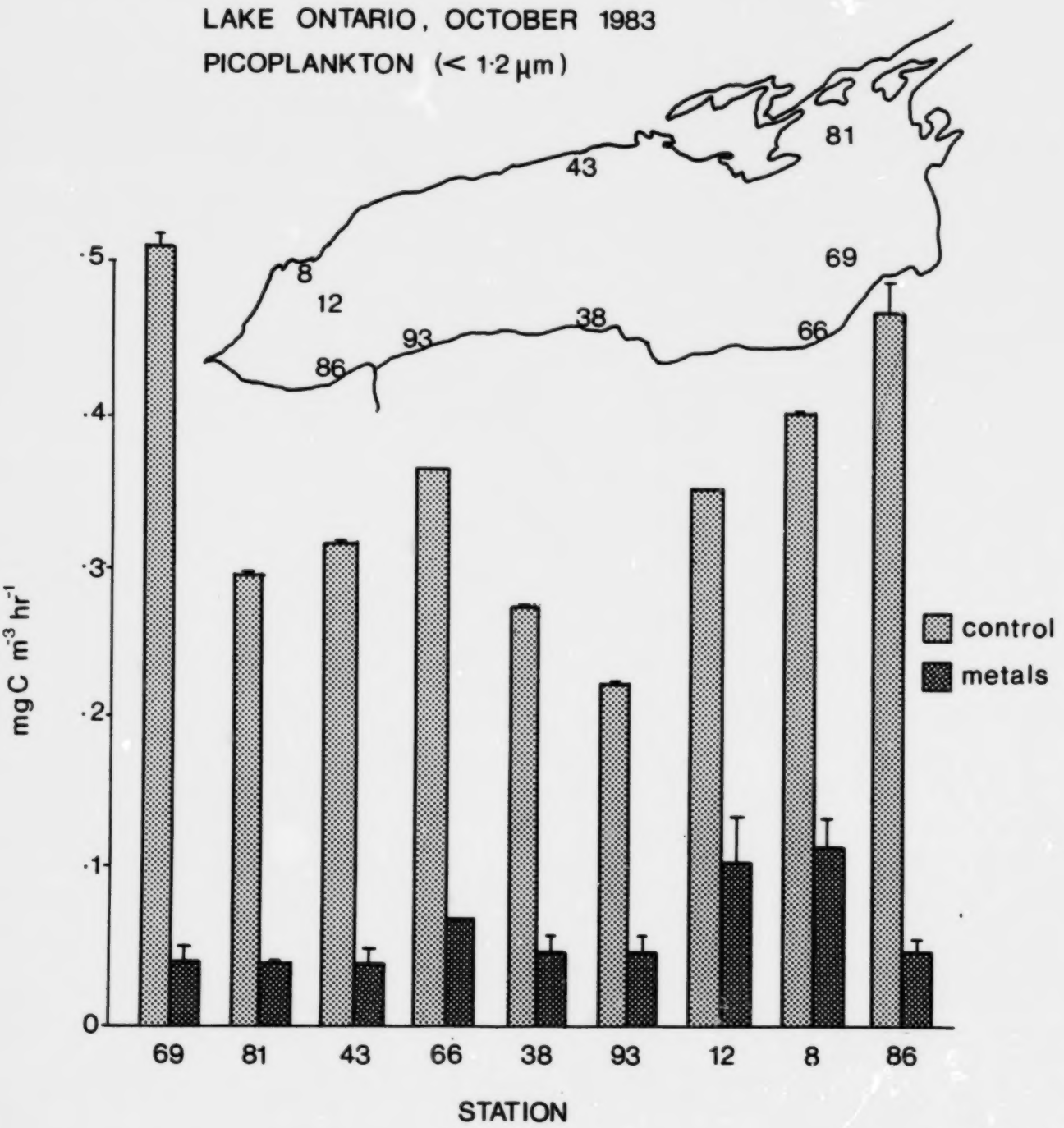


Figure 7. Picoplankton bioassays in Lake Ontario.

several laboratory and field experiments were carried out with phytoplankton and zooplankton. The commonly used elutriate test has been considered to simulate the dredging and disposal processes. Almost all the impact assessment tests include the elutriate procedure for liquid phase evaluation. In our study we tested the efficiency of the elutriate test from a variety of sediments, in terms of bioavailability of heavy metals, by means of AFB's instead of the traditional bulk chemical characterization. Both short-term and long-term bioassays, ranging from 4 to 168 hours, were conducted to determine the effects of dissolved metals on various size assemblages of natural phytoplankton.

Elutriation of sediments, its chemical analyses and then AFB's were conducted using a variety of contaminated and uncontaminated sediments. Attempts were made to streamline and simplify the application of the developed bioassay technique (AFB's) for routine assessments. Extensive sampling was done in several habitats, such as the Detroit River, Niagara River, Toronto-Toledo case study (as requested by the Dredging Subcommittee), Oshawa Harbour, Wheatly, Lake Erie, and Triangle Pond (Toronto) so that 48 elutriates were assessed with AFB's. The project also included preliminary experimental work to assess the feasibility of using algal fluorescence as an indicator of stress due to contaminants by means of a computerized fluorometric videodigitization procedure under development jointly with Dr. C. Mayfield, University of Waterloo.

The impact of elutriated sediment-associated contaminants was determined for a number of locations on the Detroit River. AFB's with the standard elutriates indicated that some locations were toxic (Fig. 8). Chelex-100

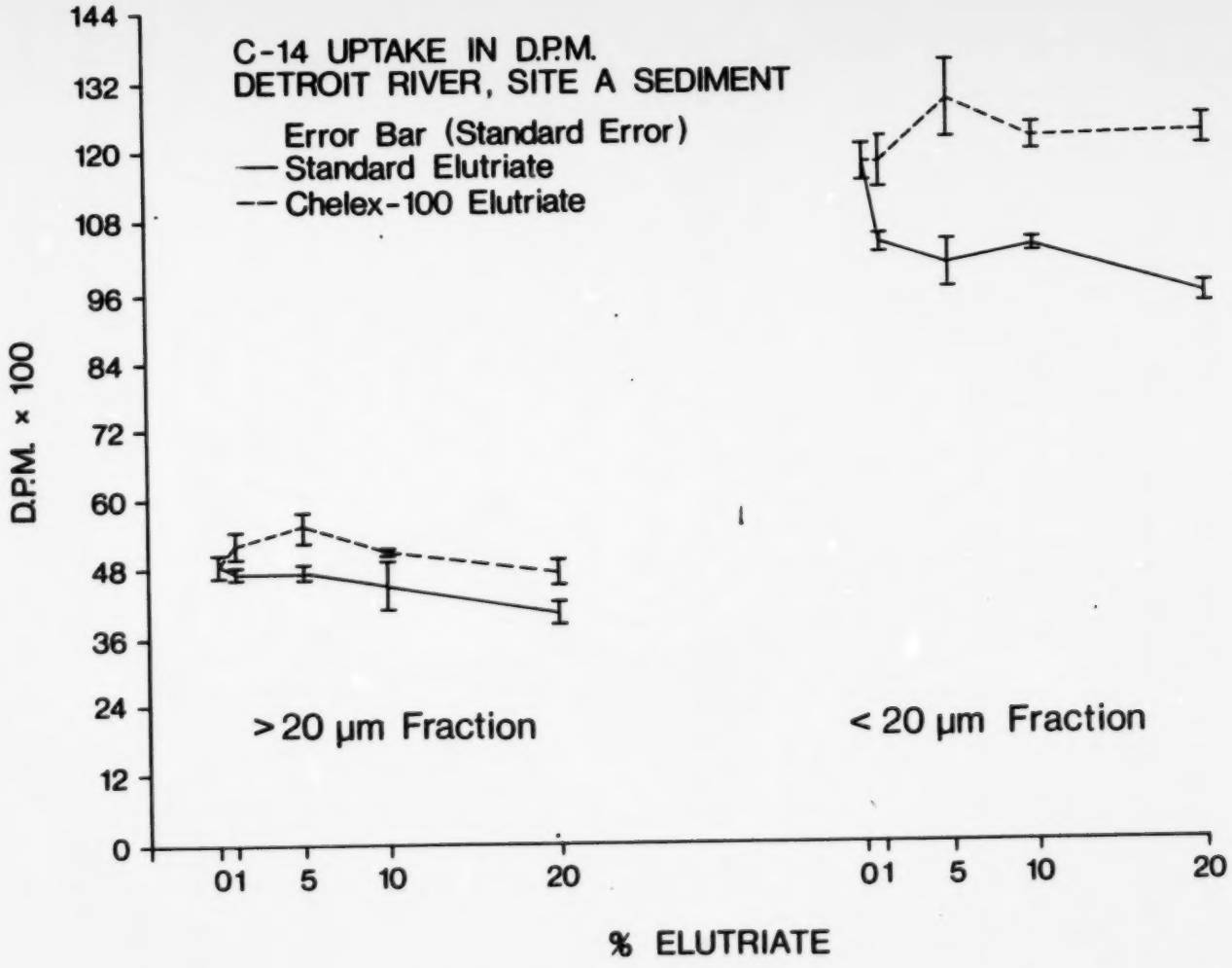


Figure 8. Sediment bioassessment of the Detroit River.

treatment removed dissolved metals and therefore caused recovery of carbon-14 uptakes indicating metal toxicity in the standard elutriates. The elutriate produced from the sediment collected from the western basin of Lake Erie appeared to be non-toxic.

Simulated dredging (by mixing the sediment with the water column) at Triangle Pond provided environmental assessment data concerning the impact of dredging activities under in situ conditions. The immediate impact of simulated dredging was a drastic inhibition of carbon assimilation (Fig. 9) and dehydrogenase activity. 100 percent recovery of carbon assimilated was not observed during the test period. AFB's were sensitive in detecting the immediate impact of contaminants and demonstrated great potential for on-site bioassessment studies. Such an in situ approach is badly needed for the evaluation of the impact of dredging and disposal activities for regulatory purposes.

Niagara River and mid-lake Lake Ontario sediment toxicities were evaluated with acute toxicity tests carried out on three crustacean zooplankters, namely Cyclops bicuspidatus thomasi, Daphnia laevis and Daphnia galeata mendotae. Mortality curves were prepared and differences between each sediment sampling station, elutriate treatment, and between each test species were evaluated by t-test and one-way analyses of variance. The results indicated, generally, that mortalities were below ten percent, although subtests mortalities had reached the 30 percent level. It was found that D.mendotae was significantly less tolerant than C.thomasi. We have now standardized experimental species and conditions.

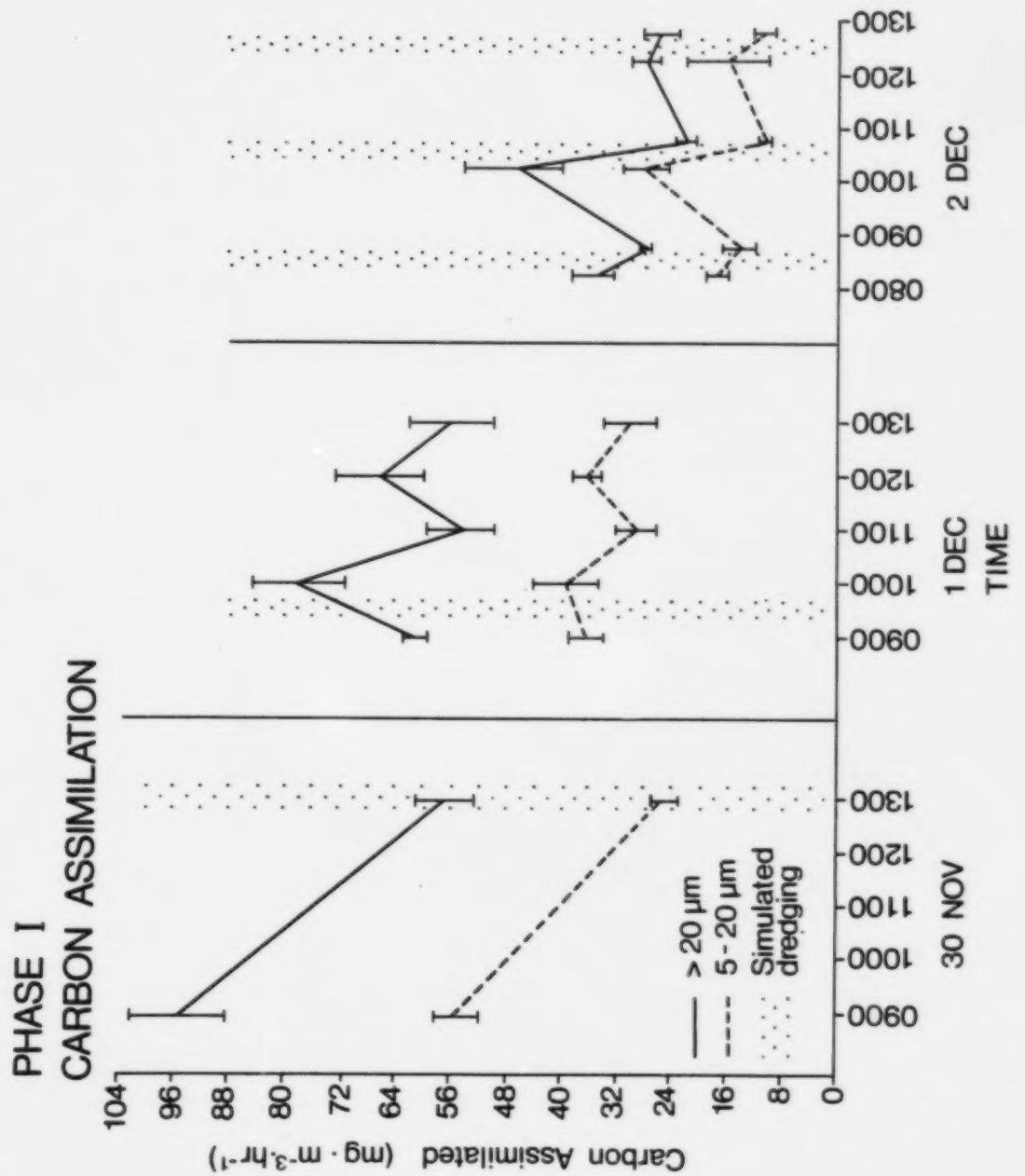


Figure 9. Simulated dredging experiments in Triangle Pond, Ontario.

This environmental assessment work included multi-agency undertakings with Small Craft Harbours, Ontario Region, the International Joint Commission, and the Environmental Protection Service, Toronto. Several papers were presented at professional meetings, of which some have been published. An in-depth overview of sediment-associated contaminants and their bioassessment has also been prepared.

E. HAMILTON HARBOUR REHABILITATION (Project Leader: Mr. V. Cairns)

E.1. Hamilton Harbour Fisheries Rehabilitation

The Great Lakes Water Quality Board, in its 1982 report to the International Joint Commission, identified Hamilton Harbour as one of the 18 'Class A' most polluted sites on the Great Lakes. The harbour, which is situated at the most western tip of Lake Ontario, consists of a deep water outer basin with an extensive shallow water marsh area to the west. The marsh area, which is called Cootes Paradise, has several tributary streams and receives municipal effluent from the Dundas and Waterdown sewage treatment plants. In past years, Cootes Paradise was heavily polluted from these sources and the marsh was extremely eutrophic. The outer harbour, which is extensively industrialized on the south shore, receives effluent from two major steel industries and two large municipal waste treatment plants.

Sediment in the outer harbour is contaminated with lead, zinc, nickel, copper, chromium, PCB's and a variety of other organic chemicals. The most polluted area is in the Windermere basin, but contaminated sediments have deposited in the central deep water basin. This basin is anoxic during the

summer months owing to the decomposition of algae and the high oxygen demand of the contaminated sediments. Hydraulic resident time in the harbour is approximately 0.25 years. This rapid exchange is partly responsible for preventing further deterioration of water quality. However, Hamilton Harbour can be considered a chemical source with unknown impact to western Lake Ontario. In addition to impaired water quality, much of the shoreline and marsh area has been filled for industrial development or dredge disposal and extensive marsh areas have disappeared.

Hamilton Harbour once supported a viable coldwater fishery in the outer harbour and a productive warmwater fishery in Cootes Paradise. These fisheries gradually responded to a variety of pressures including overfishing, lost habitat, and deteriorating water quality. By the early 1900's the coldwater fishery in the outer harbour had almost disappeared and the warmwater fishery was showing signs of deteriorating. Whillans outlined several stress periods in the Hamilton Harbour fishery beginning in the late 1800's. The last stress period occurred in 1961 and resulted in a mass emigration of fish from Hamilton Harbour into Lake Ontario. The outer harbour does not presently support any of the original species such as whitefish, lake herring, sturgeon, Atlantic salmon, or lake trout. Predominant species are carp and carp hybrids, white suckers, white perch, brown bullheads, and channel catfish.

Nevertheless, increasing environmental awareness in the 1960's focused attention on the harbour and efforts were made to reduce chemical inputs and improve the water quality. Industrial wastewater contributions to the harbour were significantly reduced by employing new waste treatment technology on

specific waste streams. Within the last five years all four sewage treatment plants have doubled in capacity and their organic contribution to the harbour has been significantly reduced. The outcome of this activity is a reversal in the deteriorating water quality of Hamilton Harbour.

There is a substantial warmwater fishery along the north shore and in the western end of Hamilton Harbour. At least 45 species were captured during 1983 and 17 of these 45 species were found as young-of-the-year, suggesting that some fish were using the outer harbour as a spawning or nursery habitat. The warmwater fishery predominates the harbour, but there are spring and fall migrations of salmonids into the outer harbour and Spencer and Grindstone Creeks.

These observations suggest that the harbour fisheries have rehabilitation potential and two literature reviews were contracted to describe the historical trends in water quality and fisheries. These reviews were intended to provide background data to support further rehabilitation efforts. In addition, a workshop was held with representatives from industry and provincial, federal, and municipal agencies, to discuss the possibility of rehabilitating Hamilton Harbour. The workshop identified areas of needed research and the major factors that are currently limiting fish production and recreational use. These include the anoxic hypolimnion during the summer months and the continuing loss of nearshore habitat (from landfilling, dredging, and dredge spoil disposal). Added to these are concerns for toxic chemicals, eutrophication, turbidity, and limited public access to the harbour. Perhaps the most important issue is the absence of long-term goals for Hamilton Harbour. The harbour serves the needs of many agencies, each one

with its own perceptions and objectives. Many of these agency perspectives are developed in isolation and activities by one user group may conflict with the goals of others. The major recommendation from the workshop was the need to establish a multi-agency steering committee to develop a strategic plan for Hamilton Harbour which is compatible with the goals of all user groups. Furthermore, the steering committee would establish data needs and identify the necessary milestones and rehabilitation sequences necessary to achieve these goals.

From a fisheries perspective, there is a need to describe the current fisheries resources of Hamilton Harbour. There are some information on species composition and the health of individuals, but very limited data describing year class strength, habitat utilization, benthic populations, and fish movement between the two basins and Lake Ontario. This work will begin in 1984.

ENVIRONMENTAL TOXICOLOGY

(Program Coordinator: Dr. P.V. Hodson)

A. CONTAMINANT DYNAMICS

B. CONTAMINANT EFFECTS

C. METHODOLOGY

A. CONTAMINANT DYNAMICS (Projects Leaders: Dr. P.V. Hodson/Dr. P.T.S. Wong/ Dr. A.J. Niimi)

A.1. Methylation and Toxicity of Lead and Tin Compounds in the Aquatic Environment

We have previously demonstrated the methylation of various lead and tin compounds in the sediments from Ontario lakes and rivers. In this study, we examined the factors affecting lead and tin methylation. We added various lead compounds such as lead nitrate, lead acetate, lead sulfide, lead oxide, trimethyllead and lead metal or inorganic tin compounds to the sterile or non-sterile sediments incubated under aerobic or anaerobic conditions, at several pH's and with and without the added co-factors (methylcobalamin, S-methylsulfonium chloride, methyliodide). Results of these experiments to date show no definite conversion of inorganic lead or lead metal to tetraalkyllead nor any effect of added co-factors. In summary, no methylation of Pb(II) compounds by sediments has been found, but evidence for a biological route from trimethyllead to tetramethyllead has been obtained. A large number of similar experiments have been carried out with tin compounds. Methylated tin compounds (monomethyltin and dimethyltin) have been detected in the

sediments, but not from the pure bacterial and algal cultures. The demonstration of lead and tin methylation would have serious consequences for water quality and for the health of aquatic biota since methylated lead and tin compounds are much more toxic than inorganic compounds.

In conjunction with the methylation studies, we have also carried out an extensive survey of the occurrence of these methylated compounds in environmental samples. To do that, we had developed sensitive analytical techniques to detect these compounds in air, water, sediment, clam, macrophyte, and fish samples.

High levels of lead compounds were found in fish taken from the St. Lawrence River near Maitland and from the St. Clair River near Sarnia (Figs. 10 and 11). This contamination was associated with alkyllead compounds in discharges from industries that make tetraethyl and tetramethyllead for gasoline (E.I. Dupont de Nemours of Canada Ltd; Ethyl Corporation).

Concentrations of total lead in the blood (0.019 to 57 mg l^{-1}) and the gutted carcass (<0.01 to 174 mg kg^{-1}) of fish sampled near the sources were the highest ever reported. A high proportion of total tissue lead (up to 100 percent) consisted of various alkyllead compounds (<0.01 to 144.5 mg kg^{-1}), particularly di-, tri- and tetraethyllead. These levels of contamination have been confirmed by five private, provincial, and federal laboratories.

Levels of alkyllead compounds in fish were least upstream of the source on each river, greatest near the sources and intermediate downstream. Contaminated fish were found as far as 40 km downstream of the source at Sarnia. Carp was the most contaminated species and high levels of alkyllead compounds were also found in other sport and commercial fish species.

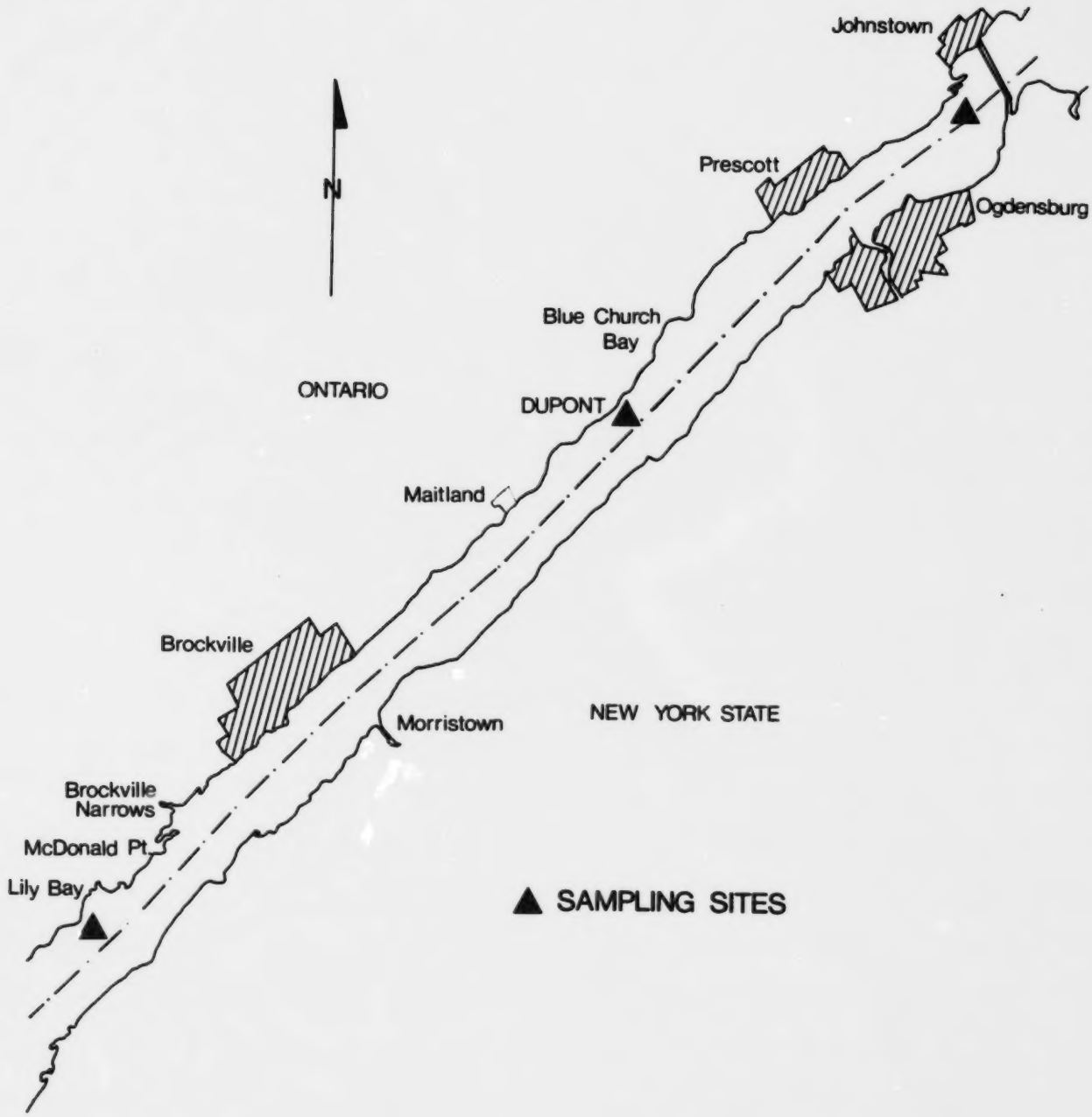


Figure 10. St. Lawrence River sampling sites.

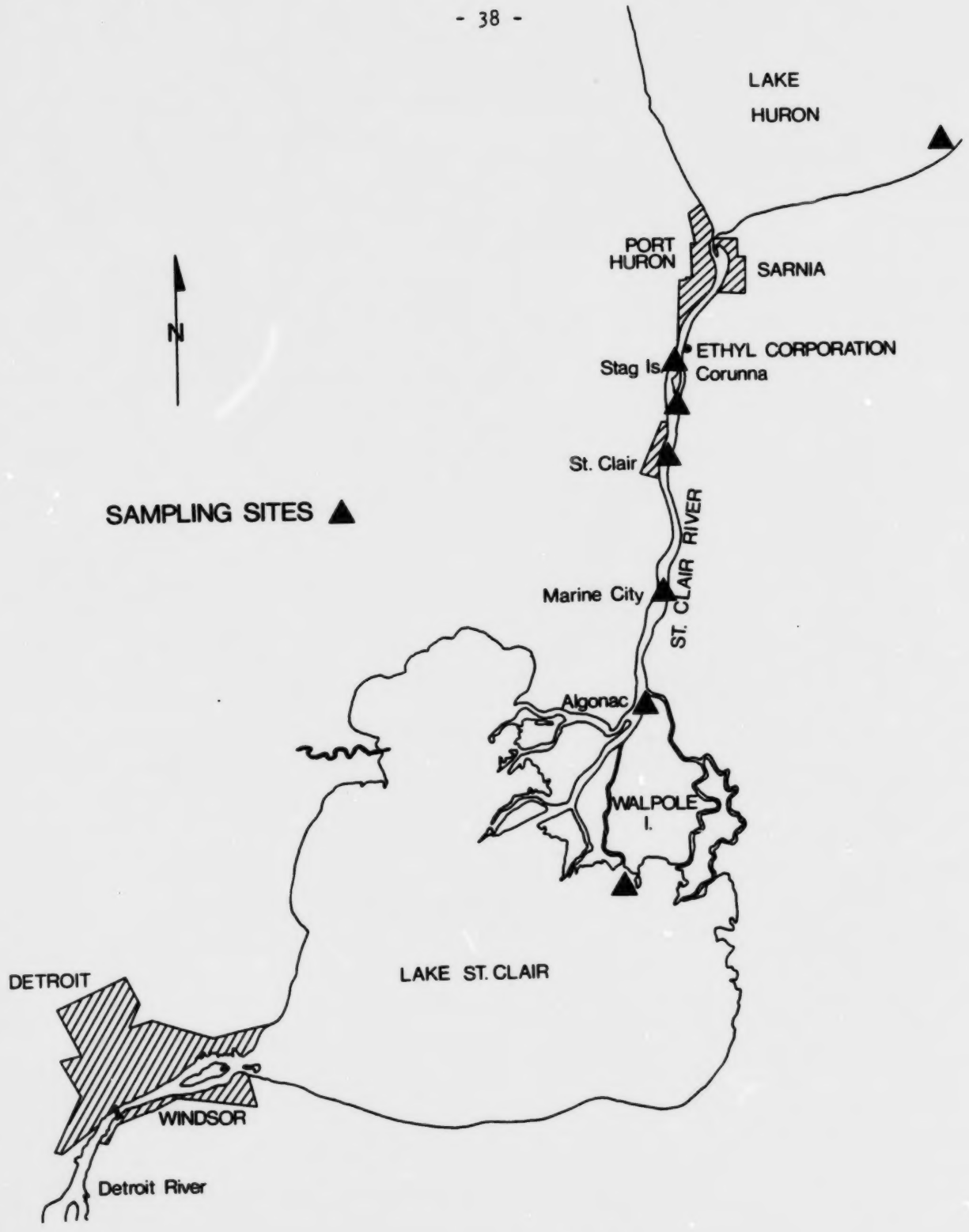


Figure 11. St. Clair River - Lake St. Clair sampling sites.

Alkyllead was also found in macrophytes (<0.01 to 28.15 mg kg^{-1}), sediments (<0.015 to 1.5 mg kg^{-1}) and water (0.1 to 0.3 $\mu g\ l^{-1}$) from the St. Lawrence River. The source of lead in the fish appears to be water, based on the relative levels of different alkyllead compounds in water and sediment, and the rapid accumulation of waterborne alkyllead compounds by fish. Nevertheless, laboratory experiments demonstrated that sediment lead was available to fish, although only in small amounts.

Levels of lead compounds in fish varied from year to year in the St. Lawrence. The highest levels were found in 1981 with lesser amounts in 1982 and 1983.

Levels of alkyllead compounds in fish muscle were equivalent to levels in gutted carcass. Therefore, alkyllead contaminated fish could pose a risk of lead poisoning to fish consumers.

The impact of alkyllead on fish is unknown although two of a sample of ten fish taken from the St. Lawrence River had histopathological lesions of spinal neurons and muscle. These fish were highly contaminated. There are also unconfirmed reports of a high prevalence of deformities in fish downstream of the source on the St. Lawrence River.

A.2. Mixed Function Oxidase Activity in Livers of Great Lakes Lake Trout

Xenobiotic chemicals from industrial and urban wastes, agricultural runoff, and oil spills have entered the aquatic environment for many years. The accumulation of organic compounds by whole organisms and, to a lesser extent, specific tissues and organs have been studied previously. Recently, interest has increased in the metabolism and biotransformation of these aromatic

hydrocarbons in aquatic biota. Many lipophilic compounds, including polynuclear aromatic hydrocarbons (PAH's), are metabolized by the hepatic cytochrome P-450-dependent mixed-function oxidase (MFO) system. Although many studies have focused on the MFO system in mammalian species, few have dealt with fish.

The activity of one MFO, aryl hydrocarbon hydroxylase (AHH), has been suggested as a useful indicator of the presence of (and response to) hydrocarbons in fish. This enzyme is rapidly induced by contaminants and elevated activity has been observed for long periods. The AHH assay is simple, sensitive, and may be automated. Using this method, hydrocarbon contamination might be identified more readily than by chemical analyses. With additional information on whole-body burdens, a more extensive and explicit understanding of the effects of contaminants on fish health might be obtained.

MFO activity of fish is often higher in polluted areas compared to non-polluted areas. Many investigators have observed elevated MFO activity of shoreline fish species after petroleum spills. Killifish showed high AHH activity in a location that had an oil spill eight years previously. Since a variety of fish species have MFO activity, it is possible to select a monitoring species to indicate either local contamination or average lakewide contamination based on migratory and feeding patterns.

In order to measure MFO activity reliably in feral fish, a few modifications in collecting and preserving samples were adapted in 1983. Efforts were made to collect and assay the fish within a 24-hour period to eliminate declines in MFO activity. To correlate feeding habits, contaminants

and MFO levels, additional parameters such as stomach contents, bile colour, and liver morphology were recorded. Bile samples were frozen for future PAH metabolite analyses. A method was developed for preserving the hydroxylated product in the MFO assay so that sampling of fish at different sites could occur simultaneously. A comparison between the Sorval ultracentrifuge and the portable Eppendorf centrifuge for MFO assays was completed.

Lake trout was chosen as this project's monitoring species because of its wide distribution, position in the food chain, graded levels of contaminant burdens in the Great Lakes, and signs of reproductive failure. Over 200 measurements of MFO activity in lake trout from clean and contaminated environments were assayed in the 1983 field season. Results indicate that there is a correlation between elevated MFO levels and areas of high organic contamination. Table 9 provides a summary of sampling sites and MFO levels for a seven-week sampling period. Shoreline species (white suckers, carp, and hybrids) also produced high levels of MFO activity in the Hamilton Harbour area, indicating a correlation with the elevated levels of organic contaminants (PAH's) found in the sediments.

TABLE 9. Aryl hydrocarbon hydroxylase activities of Lake Trout from various lakes during June and July, 1983.

	N	mg PMS PROTEIN[a]	AHH ACTIVITY[b]
Lake Opeongo	15	18.58 (±1.16)	1.71 (±0.14)
Lake Ontario (Hamilton)	12	21.42 (±1.21)	18.63 (±1.41)
Lake Huron (Grand Bend)	10	18.67 (±1.28)	0.34 (±0.04)
Lake Superior (Whitefish Bay)	7	16.10 (±2.0)	2.94 (±1.40)
Lake Superior (Silver Islet)	11	9.50 (±1.36)	0.76 (±0.23)
Lake Superior (Pie Island)	6	15.37 (±1.52)	1.31 (±0.19)

a Geometric mean and S.D. PMS = Postmitochondrial supernatant
AHH = Aryl Hydrocarbon Hydroxylase

b Fluorescence U/mg postmitochondrial supernatant protein (geometric mean and S.D.)

Since MFO enzymes normally interact with reproductive hormones, it is not surprising that MFO activity varies between sexes. This appears to be linked with gonadal maturity and/or hormonal regulation. We also observed seasonal variability which could be clearly associated with spawning and/or feeding habits. Preliminary data indicates that reduced AHH activities at spawning time. Other studies have shown a similar correlation between spawning time and lower MFO activity using other fish species such as cunner, Pacific salmon, sand dab and mummichog. Other sources of variability that have been observed are species, size/age, temperature, diet, migration and sampling method. Data analyses are still under way and will be available by early 1984.

A.3. Models

Mathematical models that describe the behaviour of environmental organic contaminants in fish can be used to assess the bioaccumulative properties of toxic substances in the natural environment. These models have generally been developed from information derived from laboratory and field studies. Much of the historical information available from laboratory studies may not be entirely suitable for this purpose because of the emphasis on lethality, use of small fish observed over relatively short periods, and exposure to concentrations that may not be representative of that present in the natural environment.

A series of laboratory and field studies were initiated to derive a better understanding of the behaviour of different groups of organic contaminants using relatively large fish exposed to residue levels that approach environmental concentrations for several months. Much of the effort has been devoted to high priority pollutants. One series of studies examined the biological half-lives of different substances in fish to better understand the elimination component of a contaminant dynamics model. A study on the elimination rates of 31 dichloro- to decachlorobiphenyl congeners in trout indicated that half-lives increased from five days to no apparent elimination as the degree of chlorination on the biphenyl increased. This observation could account for the range of half-lives reported for PCB Aroclors in the literature. This study also emphasized the need to identify the more biological and chemically active components of contaminants that are formulated as mixtures. Similar studies are now in progress to estimate the biological half-lives of two dibenzo-p-furans, five dibenzo-p-dioxins, and ten polycyclic aromatic hydrocarbons (PAH's).

Another area of investigation is the uptake of waterborne contaminants by fish. A study on the uptake of ten chlorobenzenes indicated that equilibrium values derived from laboratory studies can be used to predict residue concentrations of some substances in fish residing in contaminated environments. A second study on 12 halogenated aromatics suggested that molecular size may influence the uptake rate. This is one of the factors being examined in an ongoing study that is monitoring the uptake of 37 chemicals with different properties.

The rate constants for contaminant dynamics models have been related to the metabolic requirements of fishes. Temperature is one of the more environmentally and physiologically important factors that influence metabolic rate. To examine the extent that temperature may have on a generalized model, the elimination rates of three substances with different half-lives were examined in trout held over a 14°C range. The results indicated that temperature would have a differential effect on the derivation of the coefficient for the elimination component of a model, and that this effect would be particularly evident for those substances with relatively short half-lives.

The role of reproduction as a mechanism for contaminants elimination has generally not been included in most contaminant dynamics models. A comparative study on the redistribution of 11 contaminants in the eggs of five species of fish indicated that 6 to 26 percent of the total residues present in females could be transferred to the eggs. A good correlation was suggested between percent transfer and the percent of lipid in fish, and percent of total lipid deposited in eggs. This observation would suggest spawning could represent an

important pathway for residue elimination that would be applicable to adult fish in natural environments.

Concurrent studies were also conducted to develop a field procedure that could be used to evaluate the sublethal effects of contaminants in fish. The results indicated that hematological parameters such as packed cell volume and differential blood cell ratios may not be reliable indicators of contaminant stress because of the influence of other factors that would preclude a definitive cause-and-effect relationship.

A.4. The Toxicity, Accumulation, and Metabolism of Tributyltin Oxide by Rainbow Trout

Butyltin compounds are extensively used as anti-fouling agents because they are highly toxic to algae and invertebrates and they can be incorporated in paints. Their slow leaching from the surface of paint is an important part of their antifouling action, but in doing so they contaminate water. Organotin compounds have been found in Great Lakes waters at concentrations as high as 50 $\mu g\ l^{-1}$. This concentration is 60 percent of the level lethal to 100 percent of trout tested during a 12-day exposure.

Research in 1983/84 was initiated on tributyltin oxide (TBTO), one of the most common anti-fouling agents, to measure: (a) its lethality to rainbow trout; (b) rates of its uptake and depuration by trout; (c) its tissue distribution in trout; and, (d) its metabolism by trout.

During the months of April to August, 1983, a series of acute 96-hour bioassays were conducted using rainbow trout (Salmo gairdneri) and lake trout (Salvelinus namaycush) as the test organisms. The 96-hour LC50 for rainbow

trout was approximately 6.0 $\mu g\ l^{-1}$ (95 percent confidence limits = 5.68 to 6.34). The 96-hour LC50 for lake trout has not been calculated yet as water samples are still being analyzed, but it appears to be about 18 $\mu g\ l^{-1}$.

Considerable difficulty was encountered while calibrating the compound in the bioassay system. This was probably the result of TBTO's hydrophobic nature and its tendency to adhere to surfaces and organic compounds.

B. CONTAMINANT EFFECTS (Projects Leaders: Dr. P.V. Hodson/Dr. P.T.S. Wong/ Dr. U. Borgmann)

B.1. Effect of Toxic Materials on Zooplankton and Pelagic Production

Potential fish production and biomass have been estimated from zooplankton production and biomass in Lake Ontario. Zooplankton data were obtained from the Bioindex Program and averaged over the lake. Potential fish production was calculated using a model based on particle-size conversion efficiency, the efficiency of biomass conversion from one size of organism to another size. Estimates of particle-size conversion efficiency had previously been made using data on contaminant concentrations in Lake Ontario biota. Estimated potential fish production is 1.6×10^9 g dry weight for 500 g fish (2 kg wet weight). By expanding the previous model on production to estimate biomass over various size ranges, estimates of potential biomasses of microorganisms, macroinvertebrates, and fish were made. Predicted macroinvertebrate biomass compared favourably with the sum of mysid and amphipod biomasses obtained from the literature.

To increase the versatility of the model for predicting potential production at higher trophic levels, the effects of somatic growth and

reproduction on biomass transfer up pelagic food webs have been incorporated into the model. Whenever data on size frequency distribution and growth curves are available for any species, somatic growth and reproduction effects can be estimated. Published data on Mysis relicta abundance in Lakes Ontario and Superior have been used to demonstrate application of the model. Somatic growth enhances biomass movement up the food chain because biomass is transferred to larger organisms without direct trophic level transfer. Reproduction reduces the efficiency of biomass transfer up food webs because it results in production of individuals of small size at lower trophic levels than their parents. These two effects cancel one another whenever mortality and growth rates are balanced in such a way that cohort biomass does not change appreciably during a species' life cycle.

To estimate the possible effects of contaminants on lakewide fish production using the particle-size conversion efficiency model, knowledge of the effect of contaminants on particle-size conversion efficiency is needed. Most published studies on sublethal toxicity of contaminants provide data on growth but not feeding. Consequently, experiments were initiated to measure the effect of contaminants on growth and on feeding of larval fish on natural zooplankton populations. The use of natural prey species permits estimation of conversion efficiencies of natural and live food at natural predator-prey size ratios, thereby permitting determination of particle-size conversion efficiency. To date, preliminary experiments have provided data on the relationship between ration and growth rates for white suckers (eggs obtained from OME, Toronto) and common shiners (eggs obtained from adults collected with the help of J. Metcalfe, NWRI). Attempts at culturing larval perch have

resulted in excessive mortality. Preliminary data on cadmium effects on growth and feeding of shiners at optimum ration levels have also been collected.

B.2. The Effect of Complexation on Metal Toxicity to Zooplankton

Studies during the last year were an extension of previous work on natural conditions. Previous work showed that the EC50 (concentration immobilizing 50 percent of the animals in 48 hours) for copper toxicity to Daphnia in inorganic medium increased on a total copper basis after amino acid addition. However, the free copper ion EC50 decreased, implying that copper-amino acid complexes are toxic to Daphnia. During the past year, total and free copper EC50's were obtained for copper toxicity to Daphnia in Hamilton Harbour (Burlington Canal) and Lake Ontario water to compare with the data obtained using the inorganic medium. Free copper EC50's were estimated both by a bioassay technique and with a cupric ion electrode. The two methods gave comparable results. Total copper EC50's were elevated in natural waters compared to inorganic medium, but free copper EC50's were reduced. This implies that Lake Ontario and Hamilton Harbour waters contain complexing agents which produce toxic complexes with copper (analogous to the toxic amino acid complexes). Copper toxicity was also measured in inorganic medium to which sufficient algae (from laboratory cultures) were added to result in total copper EC50's as high as in the natural water. In this medium the free copper EC50 was not reduced, indicating that copper complexation by, or adsorption to, algae is probably not the cause of lowered free copper EC50's in natural water. These results suggest that it is not advisable to use free

metal ion concentrations as the sole means of predicting safe levels of metals in natural waters.

Several experiments were conducted to investigate confusing aspects of metal toxicity as revealed in a recent review of the literature. Of particular interest is the question of toxicity of metal hydroxide complexes. Other inorganic complexes are generally believed to be non-toxic, but the copper-hydroxide complex has been implicated in copper toxicity to fish. This is in contrast to most algal studies where toxicity has usually been ascribed to the free metal ion alone. A comparison of copper and cadmium toxicity to Daphnia at different pH values (and therefore different degrees of hydroxide complexation) was made to investigate this discrepancy. Results are shown in Table 10. On a total metal basis, copper toxicity decreased but cadmium toxicity increased with increasing pH. On a free ion basis, toxicity of both metals (estimated using copper and cadmium ion electrodes) increased with increasing pH. The copper data indicate that either 1) copper-hydroxide complexes are toxic and therefore copper toxicity is not adequately described by free metal ion concentrations alone (hence the decrease in free copper EC50 with increasing pH), or 2) copper-hydroxide complexes are not toxic, but the toxicity of the free copper ion increases with increasing pH, possibly due to decreased competition with hydrogen ions. Unlike copper, cadmium is not complexed heavily by hydrogen ions so that free cadmium and total cadmium concentrations are directly proportional at all pH values. The cadmium toxicity data clearly demonstrate that free cadmium ion toxicity is strongly related to hydrogen ion concentration and that this effect is not due to hydroxide complexation. This suggests that free copper ion toxicity is also

likely to be affected directly by hydrogen ion concentrations. There is no reason to suspect toxicity of copper-hydroxide complexes. It is therefore probably unnecessary to take into account the concentration of metal-hydroxide complexes when predicting metal toxicity. However, all models of metal toxicity should take hydrogen ion antagonism of free metal ion toxicity into account.

TABLE 10. Effect of pH on the 24-h EC50 for copper and cadmium toxicity to Daphnia magna at 20°C, ionic strength 0.01, and 1 mM calcium. Underlined values indicate EC50s with overlapping 95% confidence intervals (n = 5 or 6).

	EC50 (uM)		
	pH 7.0	pH 7.7	pH 8.4
Total metal			
Cu	0.20	0.38	0.62
Cd	23	4.4	2.0
Free Ion			
Cu	0.056	0.037	0.006
Cd	14.5	2.8	1.2

Calcium and magnesium ions often have an antagonistic effect on metal toxicity, just as the hydrogen ion does. This is particularly obvious in studies on fish. However, experiments with Daphnia this year indicated little effect of these ions on copper or cadmium toxicity in inorganic media. At pH 8.4 the copper EC50 (total metal) was 0.98, 0.62, and 0.72 uM at 0.2, 1.0, and 2.0 mM calcium respectively. Even addition of 1 mM magnesium to 1 mM calcium

resulted in an EC50 of only 0.74. At pH 7.0 the copper EC50's were 0.21, 0.20, and 0.23 uM at 0.2, 1.0, and 2.0 mM calcium respectively. It appears that metal toxicity to Daphnia is less a function of calcium and magnesium than is metal toxicity to fish.

In summary, pH affects the toxicity of free metal ions to Daphnia in a similar way as toxicity to fish. Hardness effects on toxicity are, however, different. Previous work has also shown that toxicity of copper-amino acid complexes differs between Daphnia and fish. These results, and the observations that natural complexing agents can produce metal complexes toxic to Daphnia, demonstrate that it is not possible to predict accurately metal toxicity to aquatic organisms from chemical data alone, or even from bioassay data on different organisms.

B.3. Structure-Activity Relationships in Algal Toxicology

Structure-activity correlations have been frequently used in the development of drugs and pesticides. Recently they have also been applied to fish toxicology. Algae are an essential part of the aquatic ecosystem and can be cultured and studied easily. A direct relationship between the structure and toxicity of a number of triaryl phosphate compounds as well as of the tin compounds on freshwater phytoplankton has recently been published. The object of this study was to demonstrate that such a relationship also applied to a number of chlorobenzene compounds when tested against axenic cultures and cultures of mixed, natural phytoplankton from the Great Lakes. The results from this study will supplement studies with fish for evaluating structure-activity as a tool for predicting the toxicities of organic chemicals.

The effects of benzene and 12 chlorobenzenes were tested for their inhibition of the primary productivity (14_C-method) of a pure culture of the alga Ankistrodesmus falcatus. The EC50S (effective concentration (mg/L^{-1}) that reduced 50 percent of the primary productivity) were calculated: benzene(310); MCB(50); 1,2-DCB(20); 1,3-DCB(23); 1,4-DCB(20); 1,2,3-TCB(6); 1,2,4-TCB(6); 1,3,5,-TCB(9); 1,2,3,4-TTCB(4); 1,2,3,5-TTCB(3); 1,2,4,5-TTCB(5); PeCB(1); HCB(non-toxic). The least toxic compound was benzene with an EC50 of 310 mg l^{-1}. The toxicity increased with the degree of chlorination in the benzene ring. In contrast to triaryl phosphate compounds, there was no significant difference between the isomers of the chlorobenzenes. For instance, the EC50S of 1,2-, 1,3-, and 1,4-dichlorobenzenes were quite similar (20 to 23 mg l^{-1}). The most toxic chlorobenzene tested was the pentachlorobenzene with an EC50 of 1 mg l^{-1}. Hexachlorobenzene, due to its extremely low water solubility (about 5 mg l^{-1}), had no effect on the algae. Similar observations have been reported with HCB in fish and other organisms. The quantitative relationship between water solubility, octanol-water partition coefficient and EC50 is shown in Figure 12. The observed toxicities can be predicted from the linear regression equation

$$\text{Log}_{10} \cdot 1/\text{EC50} = 0.232\log_{10}P + 4.884 \quad (n=12,\ r^2=0.874)$$

As seen from the equation, the toxicity of chlorobenzenes correlated well with the lipophilicity ($\log_{10}P$) of these compounds.

Apart from examining the toxicity of chlorobenzenes in pure algal culture, we also carried out in situ toxicity testing in phytoplankton from Lakes Ontario, Erie, Huron, and Superior, as well as from Little Turkey Lake in

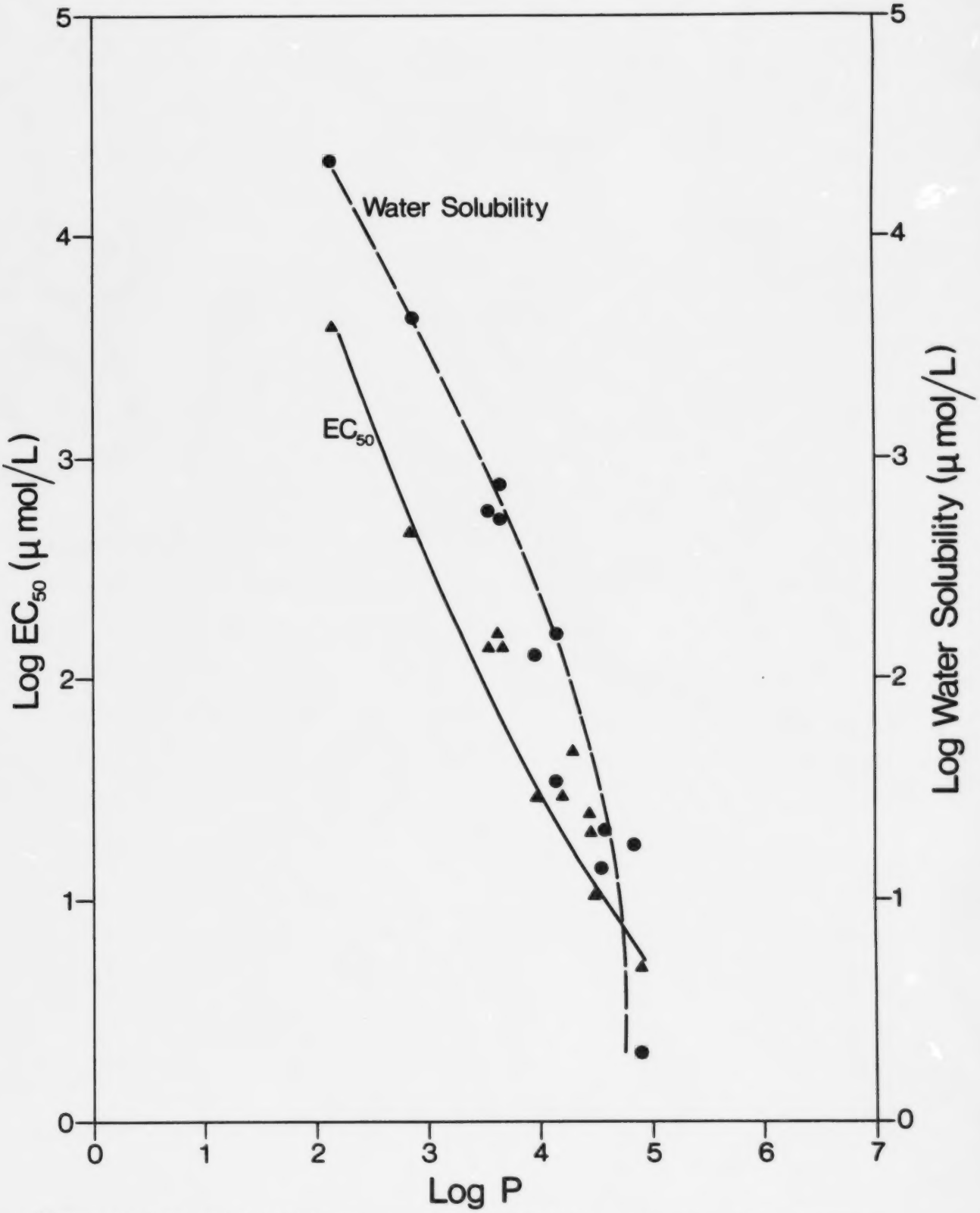


Figure 12. The relationship between water solubility, octanol-water partition coefficient, and EC50.

Ontario. We are currently analyzing the results. Our future work will examine the ability of algae to accumulate these compounds and the relationship between bioconcentration and toxicity of the chlorobenzenes.

B.4. Quantitative Structure Activity Relationships (QSAR's): The Toxicity of Phenols, Chlorophenols, and Chlorobenzenes to Fish

This project was initiated in 1979 to develop QSAR's relating structures of chemicals to their toxicity to rainbow trout. Bioassays of both acute lethal (median lethal concentration - LC50; median lethal dose - LD50) and chronic sublethal toxicity (embryo/larval bioassays) were conducted to determine whether short-term QSAR's could adequately predict long-term effects. Measurements of acute liver damage by serum enzyme assays (sorbitol dehydrogenase - SDH) provided QSAR's of one of the suspected modes of toxicity for further correlation to chronic toxicity. Results with plasma leucine aminonaphthylamidase (PLAN) were less encouraging. Finally, contract research on a new in vitro rainbow trout gonad (RTG) cell attachment assay demonstrated some potential for a more efficient bioassay to replace standard whole-fish aqueous toxicity tests (LC50's).

The above research provided data on LC50's (21 chemicals), LD50's by intraperitoneal injection (41 chemicals), LD50's by oral intubation (14 chemicals), the threshold dose causing liver damage (elevated serum sorbitol dehydrogenase) (18 chemicals), the threshold aqueous concentration for chronic toxicity (8 chemicals), and the EC50 for in vitro cell attachment (12 chemicals). Groups of chemicals were also identified that caused kidney damage (reduced plasma protein) and hemolytic anemia.

ACUTE LETHAL TESTS. Preliminary analyses demonstrated QSAR's relating LC50's of chemicals to the log of their octanol-water partition coefficient (log P). There may also be similar relationships of chronic toxicity to log P. LD50's were not related to log P since partitioning from water to lipid was not part of the LD50 bioassay. Instead, LD50's and measures of liver damage could be related to steric factors such as molar refractivity. The toxicity of chemicals measured by IP LD50's was linearly related to OI LD50's, but LD50's varied as the square of the LC50's. This curvilinear relationship could be made significantly stronger when LD50's were divided by log P, due to the effects of lipophilicity on the partitioning of chemicals from water into fish. Lipophilicity accounted for a significant proportion of the variability in measurements of toxicity.

SORBITOL DEHYDROGENASE. In preliminary trials, intraperitoneal injections of phenol, nitrophenol, methylphenol, or chlorophenol resulted in a dose-dependent increase in serum sorbitol dehydrogenase (SDH), relative to controls, either 48 or 96 hours after treatment. The order of toxicity of the chemicals, in terms of the magnitude of the 96-hour response was as follows: methylphenol>nitrophenol>phenol=chlorophenol. The optimal time for blood sampling with respect to SDH was 48-hour post injection, and freezing in liquid nitrogen was the only suitable method for storing serum samples prior to analysis.

Serum protein levels decreased with dose in all experiments, although both the consistency and magnitude of the response were reduced relative to that shown by SDH. No consistent patterns of response were apparent for either hematocrit or liver/body weight ratio. QSAR's were developed for a small number of chemicals tested using a standardized method.

PLASMA LEUCINE AMINONAPHTHYLAMIDASE. A currently available technique for the determination of PLAN activity in rainbow trout was tested and adopted. In addition, it was determined that intraperitoneal dosing of rainbow trout with para-methyl phenol caused a dose-related increase in PLAN, with a maximum level of activity being reached 96-hour postinjection. However, dose-response curves for other chemicals were not as consistent. Dietary carbohydrate level influenced PLAN response in both toxicant-dosed and control rainbow trout. As well, the temperature and duration of plasma storage influenced PLAN activity. The difficulties in generating good dose-response relationships and the number of factors affecting the measured activity made this bioassay a poor tool for QSAR studies.

CELL ATTACHMENT ASSAY. Dr. Neils Bols of the University of Waterloo developed a bioassay for rainbow trout gonad cells (RTG-2) grown in culture. The bioassay measured the cells' ability to attach to a growth surface after a 30-minute exposure to a medium containing a test chemical. The toxicity was expressed as the median effective concentration (EC50) preventing cell attachment. A ranking of the toxicity of 12 chemicals was in close agreement with that derived from traditional measures of trout LC50's. The data were used in a good QSAR relating EC50's to log P.

EMBRYO/LARVAL ASSAYS. The studies of chronic toxicity of phenols to fish suggested a common mode of toxicity: interference with energy utilization. Therefore, phenols should provide a useful model for developing QSAR's based on acute bioassays using energy metabolism to predict chronic toxicity.

QSAR DEVELOPMENT. Statistical analyses remaining from the 3-year project include the relationship of acute to chronic toxicity, the relationship of fish to mammalian toxicity and the development of QSAR's for different subsets of the same data. While statistical analyses are incomplete, the early QSAR's provide encouraging evidence that application to fisheries protection is practical.

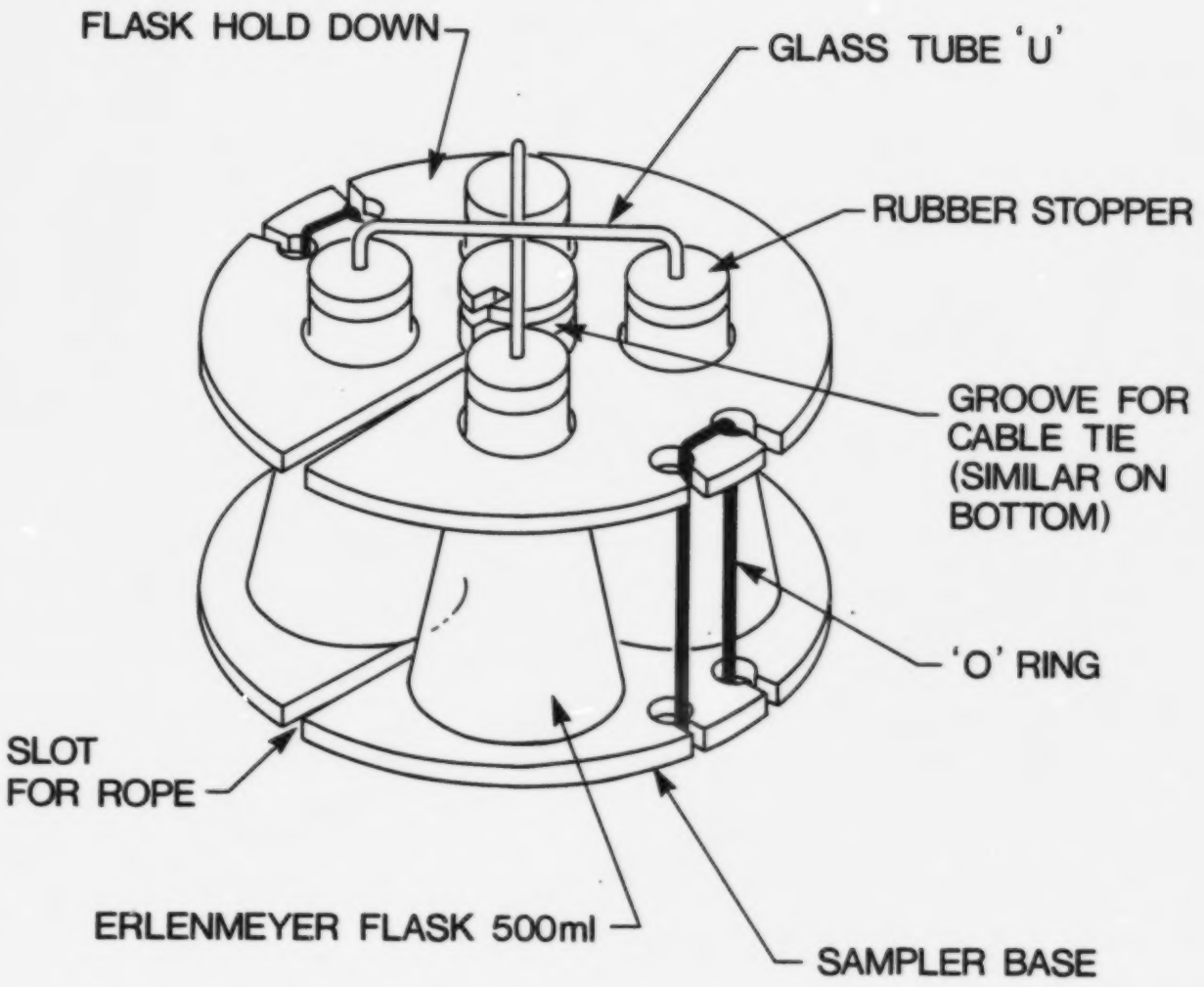
C. METHODOLOGY (Project Leader: Dr. P.T.S. Wong)

C.1. Ultra-clean Techniques in Assessing Metal Effect on Lake Superior Phytoplankton

Many studies on primary production have been carried out in Lake Superior in the past. Recent publications in the literature have shown that phytoplankton are very sensitive to metals. Therefore, unless special ultra-clean precautions are taken when sampling in very clean waters such as Lake Superior, severe contamination by metals may occur, affecting primary production estimates.

The potential sources of metal contamination associated with the primary production measurements may include sampling procedures, reagents, and glass incubation bottles.

To reduce as much as possible errors in sampling procedures, we designed a relatively 'metal-free' <u>in situ</u> water sampler. The anchor and sampling lines were made of polypropylene ropes; messengers were of porcelain; samplers were of clear plastic with four slots to hold four 500 ml polycarbonate flasks (Fig. 13). Two glass U-tubes connecting the flasks could be broken with the



IN-SITU SAMPLER

Figure 13. The relatively 'metal-free' in situ water sampler.

messenger to allow water to enter the flasks. Apart from the in situ sampling and incubation technique, we also compared various samplers for collecting water, such as Van Dorn, Niskin and Go-Flo bottles, a March Pump, and a rubber-and-plastic hand-operated pump. Since the Van Dorn sampler has many metal parts and fittings, and has been routinely used in taking water samples for primary productivity studies, we used it as an example of the conventional sampler. As for the 'metal-free' sampler, we chose the rubber-and-plastic hand-operated pump because of its convenience and non-metal components. To further eliminate metal contamination, we used high purity chemicals and reagents, as well as thoroughly cleaned glassware according to published procedures.

Due to the lack of ship time and field support, we were able to carry out only a few experiments in Lake Superior and Little Turkey Lake, Ontario. The results indicated no significant difference in the concentrations of metals (Cu, Zn, Ni, and Pb) in the waters collected by the conventional or metal-free samplers. Consequently, the primary productivity as measured by the 14-C method was quite similar in the waters. However, there was a striking increase in the primary productivity in Lake Superior water when polycarbonate bottles were used as the containers instead of the conventional glass bottles (Table 11). Similar observations were found in Little Turkey Lake water. The higher productivity in polycarbonate bottles may be attributed either to the greater transmission of light by polycarbonate relative to glass or to the release of toxic metals from glass.

Our results, nevertheless, suggest that the conventional technique of measuring primary productivity with glass containers grossly underestimates the productivity of a lake. In addition, our results also show that the addition of a metal mixture of Cu, Zn, Ni, and Pb at the Great Lakes Water Quality Objective levels (Table 11) to the water drastically reduced the primary productivity by 41 to 73 percent as compared to water without the metal addition. This reduction indicates that the water has little complexing capacity for the metal and thus a slight increase in metal contamination would inhibit the primary production of the water.

TABLE 11. In situ measurement of primary productivity with glass and polycarbonate (P.C.) bottles and metal mixture toxicity (Lake Superior, August 12, 1983).

Addition	Glass bottles Sample number	dpm/500 mL[B] (mean ± SE)		% of control	Polycarbonate bottles dpm/500 mL[B] (mean ± SE)		% of control	Productivity Ratio P.C./ glass
None (control)	10	4,125	205	100	13,715	1,076	100	3.3
Metal mixture[A]	3	2,425	288	59	3,704	193	27	1.5

[A] Metal mixture contained Cu(5), Zn(30), Ni(25) and Pb(25) ug/L.

[B] Disintegrations per minute per 500 mL of sample = a measure of $^{14}CO_2$ taken up by algae.

FISH HABITAT STUDIES

A. LONG RANGE TRANSPORT OF ATMOSPHERIC POLLUTANTS

B. FISH HABITAT/PRODUCTIVITY STUDIES

A. LONG RANGE TRANSPORT OF ATMOSPHERIC POLLUTANTS (Project Leaders: Dr. J.R.M. Kelso/Dr. C.K. Minns/Dr. M.G. Johnson)

A.1. Turkey Lakes

The Turkey Lakes watershed, located 50 km north of Sault Ste.Marie, Ontario, is one of a series (5) of calibrated watersheds across eastern Canada. This series of four lakes receives 'moderate' sulphate deposition (20 to 30 kg ha^{-1} yr^{-1}) which falls on a poorly buffered watershed, i.e., terrain poorly supplied with calcium carbonate and other natural substances which neutralize acid. The studies at this watershed are undertaken jointly by limnologists and foresters from the Department of the Environment, fishery biologists from the Ontario region of the Canadian Department of Fisheries and Oceans, and biologist and scientists from provincial government agencies and universities.

The objectives of the studies are: (i) to link atmospheric contamination to biological effects; (ii) to gauge the impact of 'moderate' sulphate deposition upon a sensitive aquatic system; and, (iii) to serve as an index against which deposition can be related to effect. Overall, the studies are directed as much to determining processes as describing effects.

Our fisheries biologists have conducted mark-capture experiments on the major fish species of each lake, sampled stream resident fish, routinely sampled of phytoplankton and zooplankton, and sampled the benthos. These studies enable us to determine the community structure, biomass, and

production for each trophic level within the biological system. Metal contaminant levels in sediment cores, together with 210 Pb dating, were employed to determine temporal trends in metal loadings to the lakes.

The chain of four lakes in the Turkey watershed provide us with a gradation from low pH/alkalinity in the headwater to moderate pH/high alkalinity at the bottom of the chain. There are no fish in the headwater lake, but caged fish placed there survive. Further experiments will be devoted to testing if the 'no fish' situation is due to acidification.

Fish standing stocks in the lakes increase with increasing downstream alkalinity and salmonid production increases. In the streams there are low standing stocks of fish and streams appear to be used seasonally by lake resident fish. Stream invertebrate standing stocks vary from low, just below the headwater lake, to high, downstream of the most alkaline lake, but have good species diversity. Benthos studies in the Turkey lakes did not reveal any strong correlations with pH or alkalinity. There was a slight shift in community composition and an increase in Chironomus anthracinus at low pH's. Littoral fauna showed no change in numbers, but did show a significant increase in biomass at lower pH's, due to an increase in larger species normally susceptible to fish predation.

A.2. Mesoscale Studies

A DFO workshop, sponsored by GLFRB, 1982, identified deficiencies in data and uncertainties with regard to acidification mechanisms. In response to needs, a Mesoscale Study with four small watersheds (about 200 lakes in each), was intensively sampled to characterize intra- and inter-regional variability (Table 12). Although all watersheds are on the Canadian Shield, marked differences in their chemistry and biological communities exist.

TABLE 12. Percent distribution of lake pH from intensive mesoscale watershed surveys in Ontario, 1983.

Location	pH				
	5.0	5.5	6.0	6.5	
Sequin and Shawanaga Rivers near Parry Sound (N = 78)	3.85	20.51	30.77	42.31	2.56
Mahzenazing River near Killarney (N = 48)	39.6	22.9	25.0	12.5	0.0
Rapid River near Sault Ste. Marie (N = 51)	0.0	0.0	7.8	15.7	76.5

With OMNR, some 150 lakes from these watersheds were sampled to determine community structure and, in part, an index of fish standing stock. Lakes in the Rapid River watershed supported largely salmonids (lake and brook trout), suckers, and cyprinids. Fish species in the Mahzenazing system included lake trout, whitefish, pike, centrarchids, yellow perch, white sucker and cyprinids. In the Shawanaga, the most widely distributed species were centrarchids, yellow perch, and brown bullhead but lake trout, walleye, and northern pike were also collected in a few lakes. Common fish species in the Seguin system included yellow perch, centrarchids, white sucker, brown bullhead and cyprinids.

Since the fishery data from the watersheds tends to be qualitative rather than quantitative, a mark-recapture program to determine standing stock and production is being planned. Also, with OMNR, we are examining, methods of

estimating yield/production for Canadian Shield lakes using the primary literature and creel census data.

A.3. National Inventory Survey Analysis

In 1979, DFO began a survey of headwater lakes in eastern Canada, the National Inventory Survey (NIS), to determine the status of freshwater fisheries and their habitat in relation to atmospheric deposition. These data could be used as a baseline against which future changes could be gauged. Further, these data serve as input parameters for models or as a basis to validate at least some of the model assumptions. Finally, although there had been other regional syntheses of the status of freshwater resources in Europe, most North American studies failed to reflect regional differences that must exist because of differences in atmospheric deposition and sensitivity - this was the primary focus for the study.

Initially, sensitive, undisturbed headwater lakes were chosen. Later, in Labrador and Quebec, higher order lakes were selected in terrain of varying sensitivity. This reflected the fact that many of these regions had never been surveyed for any fisheries reason in the past. The sampling program was designed to provide a snapshot of each lake, its chemistry and biota, and, in some cases, its fish community.

In eastern Canada, there are 162,000 km^2 of lake surface south of latitude 54 and, of this, 62 percent, or 250,000 lakes, have alkalinities less than 100 $\mu eq\ l^{-1}$. These lakes and associated biota must be considered highly susceptible to the impacts of acid rain. All indicators (Table 13) point to the fact that waters, and consequently the fisheries resource, of Nova Scotia are by far the most susceptible to effects from LRTAP.

TABLE 13. Summary of lake sensitivity indices for surveyed lakes in Eastern Canada.

	Lakes with CSI>3	Lakes classed as "acidified"[1]	Lakes with Alk 100 µeq l^{-1}	Mean	Lakes with pH
pH<6					
Ontario	61.8	1.6	50.0%	5.8	22.9%
Quebec	72.6	1.4	72.3	6.1	16.3
Nova Scotia	95.0	47.3	97.2	4.9	73.7
New Brunswick	71.7	15.4	79.7	5.6	35.3
Newfoundland	87.0	4.0	82.4	5.7	46.3
Labrador	92.3	-	86.9	6.1	16.2

[1] from Henriksen 1980.

Throughout eastern Canada, the trend of fewer species of fish, phytoplankton, zooplankton, and benthos below pH 6 persists. This response necessitates broadening the area of concern to include systems with pH levels up to and including pH 6. It is also apparent from this analysis that not only are there fewer and more acid-tolerant species in lower pH lakes, but also that the number of fish caught decreases with decreasing pH in most regions. This empirical relation suggests that not only are lakes with low pH carrying a community with diminished species richness, but also that production of fish is less in acidified systems.

In the biological community, the least response is seen in the benthos. However, this is not unexpected as members of the benthic community tend to receive the benefits of buffering from their substrate.

Metal body burdens increased in fish from Nova Scotia and New Brunswick with decreasing pH and alkalinity. These waters were classed as the most susceptible to acidification (Table 13). All regions had high levels of one

or more metals in fish that were similar to levels reported from areas of known contamination.

The range in aluminum levels of lakes in eastern Canada are midway between the non-acidified and acidified lakes in Scandinavia. Overall, aluminum is related to lake pH, but there are regional differences in availability of the metal with Nova Scotia having generally higher values. Manganese was related to pH in New Brunswick which, along with Nova Scotia, had the highest mean concentrations in eastern Canada.

Copper and nickel were also related to lake pH in Ontario and Quebec where levels spanned the greatest range. In fact, some copper concentrations exceed levels known to cause behavioural and growth effects. Since trace metals are implicated in the effects observed during lake acidification, those regions of Canada with greater availability of metals conceivably suffer a greater impact.

Difference among lakes of eastern Canada is largely attributable to variations in their buffer status, i.e., alkalinity, Ca, Mg. When these lake descriptors and other dominant characteristics - trace metal levels, Al, Mn - are examined in light of lake geographic location or differences in atmospheric deposition, although the relation is not definitive, deposition provides a better means of predicting lake conditions than geographic location.

Overall, since 62 percent of lakes studied have alkalinities less than 100 ueq l^{-1} and 29 percent of the overall sample were lakes with pH values less than 6, a great proportion of eastern Canada's fishery resource is at risk.

A.4. Large-scale Risk Assessment

As part of Ontario's contribution to the National DFO Program on Acid Rain,

GLFRB has undertaken to develop estimates of the current and future extent of the impact of acidic loading on lakes and rivers in eastern Canada.

In 1983 there were five aspects of the ongoing activity:

(i) A contract was released to secure an important data base on lake areas and drainage areas in 30 watersheds across the Canadian Shield.

(ii) Further analysis of earlier regional models was undertaken. A report is now being written.

(iii) GLFRB supported an unsolicited proposal to DSS to develop predictions of acid rain impact on fishery resources, with confidence limits. This project is under way but will not be complete until mid-1984.

(iv) Dr. Minns was invited by staff in the Fisheries Branch of OMNR to continue earlier analyses of the sensitivity and potential loss of fishery resource in Ontario using new assemblages of fishery resource and chemical sensitivity data. This work is continuing at a low level determined by the speed of data assembly.

(v) GLFRB and OMNR staff collaborated in model development ensuring co-ordination and complementary of efforts. Our models are extensive/long range while theirs are intensive/medium range, i.e., multilake/regional vs single lake/watershed.

A.5. Effects of Airborne Pollutants on Aquatic Communities of Lake Huron/Georgian Bay

During 1983 a total of 54 stream and snow samples were collected over four separate runs. During August-September, five more study areas were added to the data base. These include Byng Inlet, Bayfield Inlet, Shawanaga Inlet,

Parry Sound, and Moon Bay. Sediment and core slices from these areas have been submitted to Barringer Magenta for metals analysis. Core slices from 20 separate locations have been submitted for Ambrosia pollen analysis. Fish sample preparation for metals analysis is in progress. All data available to date have been entered into computer files.

Principal components analysis and community similarity coefficients in benthic macroinvertebrates are continuing to search for differences and similarities among the bays examined (e.g., McGregor Bay, Bay Finn, Beaverstone Bay, etc.).

General conclusions are as follows: almost all rivers show significant alkalinity loss and those rivers draining from the Sudbury area have considerable excess SO_4 as well as elevated metal concentrations.

Depressed pH's and alkalinities are locally detectable at spring freshet time in bays, e.g., Collins Inlet, and Beaverstone, Iroquois, McGregor Bays.

Elevated modern loading rates to sediments are found for Pb, Cd, Zn, and Hg.

High metal levels were found in surface sediments in most bays, often (>50 percent) in excess of polluted guidelines for Pb, Cd, Ni, Zn, and Cu. Georgian Bay sediments show least enrichment.

Macroinvertebrates occurred in ten main community types; discriminant function analysis showed strongest influence by loss on ignition, percent silt in sediments, alkalinity, and lead concentration in sediments. Numbers and diversity of chironomids in cores decreased toward the surface of cores.

B. **FISH HABITAT/PRODUCTIVITY STUDIES** (Projects Leaders: Dr. J.R.M. Kelso/ Dr. M.G. Johnson/Mr. R.M. Dermott/Mr. J.K. Leslie)

B.1. Project Quinte

1983 was a year of change for this Project. While there was increased emphasis of analysis and documentation of the results so far, the field program was drastically reduced to a level that is economic while continuing to provide adequate information on changes now and in the future.

As of May, 1983, the majority (20) of the planned papers had been reviewed in first draft form by the publication committee. During the summer of 1983, a synthesis phase was begun with components addressing Nutrient Dynamics, Trophodynamics, Variability and Management. As of October, 1983, there had been significant progress particularly with the Nutrient Dynamics component. By October, more than half of the manuscripts were available in second draft form.

The highlights of the Project so far can be stated as follows:

(i) Summer point source loading reduced from 200 kg day^{-1} (1972-1977) to 70 kg day^{-1} (1978-1981).

(ii) Upper Bay of Quinte shows no retention of P during the summer; internal loading is extremely important.

(iii) Middle and Lower bays are strongly influenced by water exchanges with Lake Ontario.

(iv) Algal biomass and production rates significantly reduced and no change in composition.

(v) Decreases in zooplankton biomass and production, but no consistent changes in composition (1975-1981).

(vi) Benthic community shows little change except for 'recovery' of Pontoporeia in Lower bay which is correlated with changes in white perch population, a main predator.

(vii) Macrophyte community shows no recovery.

(viii) Fish community has undergone major change, but not apparently due to changes in nutrients. Yellow perch has been increasing throughout the 1970's. Spring, 1978, late winter die-off of most white perch, then the dominant species. Walleye produces strongest year-class ever that spring. Other predators, such as pike and bass, have shown increases. Alewife has declined.

(ix) Current nutrient loading prognosis is good especially if point source controls are consistent and 0.5 mg l^{-1} is maintained for the summer period.

(x) Prognosis is that further improvement can be expected as sediment P in the Upper bay is diluted in the future. A long-term downward trend in rates (P) is expected and the Upper bay should begin to retain P in the future.

(xi) Fish community fluctuations should continue for some time, affecting zooplankton and benthos composition.

(xii) Macrophytes are expected to recover, further enhancing the recovery sequence.

(xiii) Low level monitoring is needed in the future to complete documentation of recovery and to protect against any backsliding.

The 1983 Program was the first of the new reduced Program. Sampling was carried out in cooperation with OMNR using the Research Vessel 'Namaycush'. A

bi-weekly program was conducted during May-October, with samples for nutrients, algae, and zooplankton being collected at three stations. In addition, the benthos index series was repeated. The zooplankton samples for Belleville and Conway for 1982 and 1983 were counted. The benthos samples for 1982 were picked and counted. OME provided algal and nutrient analysis support through the regional office.

In addition, some fishing experiments were conducted to examine assumptions implicitly used in the analysis of index gillnet catch data. This was done jointly by staff from GLFRB and OMNR. A further limited study was done to try to explain N-S gradients in algal biomass which were observed in the Lower bay in 1982. There was no evidence of different water masses based on horizontal temperature and conductivity profiles. The paper writing for the 1972-82 phase of the Project will be completed early in 1984 and once the editorial process is complete, publication will occur in late 1984 or early 1985.

It is planned that the low level monitoring activity will continue in 1984 and succeeding years. In 1985 or 1986, the macrophyte surveys will be repeated. The future of the Project will be reviewed again in 1987.

B.2. Larval Fish

Larval and juvenile fish in Mitchell Bay, Lake St.Clair, and environs, were sampled on 17 occasions from early March to mid-November, 1983. Approximately 26,000 young fish were caught in 300 samples. Cursory examination in the laboratory of the samples indicated at least 25 species were present, the most abundant being yellow perch, crappie, gizzard shad, alewife, spottail shiner,

and sunfish species. Prolonged cold, wet weather during the spring probably delayed or interfered with spawning activities of at least some early spawners such as walleye, northern pike, and muskellunge. Follow-up sampling during early 1984 is planned in order to better describe the dynamics of the Mitchell Bay larval fish population.

Taxonomic description of larval muskellunge, Esox masquinongy, has been completed, and grass pickerel, E. americanus; northern pike, E.lucius; and common shiner, Notropis cornutus, have been partly described.

A number of observers, with various degrees of skill and experience, took part in a study of the accuracy of micromeasurement as applied to larval fish research. Results will be submitted for publication in the new year.

B.3. TFM Report

Seventy-six pre- and post-treatment invertebrate samples were collected from Soper Creek, Bowmanville, on May 3 and 10, 1983. This hardwater (alkalinity 222) Lake Ontario tributary was treated May 6 at a target level of 6.5 ppm lampricide containing 0.8 percent Bayer. Invertebrate drift samples were also collected below the former application site at the Pine Ridge Institute dam. Pre- and post-treatment drift samples were collected May 3 and 10, together with samples on May 6, with samples collected between 0900 and 1800 hours.

Analysis of the numbers in the surber samples indicated that few insects were affected by the treatment, with slight reduction in the numbers of Hydropsyche and Diamesia ($p=<.05$, $df=20$). However, the thin cuticle annelids were significantly reduced with the fish leech Piscicola showing heavy mortality ($p=<.01$), while the oligochaetes Stylodrilus and Nais showed slight

reduction ($p=<.05$). The drift samples collected before and during the lampricide treatment showed significant increases in the numbers of leeches, oligochaetes, blackflies, and craneflies in the water during treatment. No changes in the mayfly populations of Baetis, Paraleptophlebia or Ephemerella occurred, while the number of blackflies in the surber samples increased after treatment probably due to increased drift from upstream.

A total of 69 pre- and post-treatment surber samples were collected in the Goulais River, Achigan Creek system June 14 and July 7, 1982. This softwater tributary of Lake Superior (12 meq in Achigan, 20 meq in Goulais) was treated with 1.3 ppm TFM on June 15. At sites above and below the application point in the Achigan, the invertebrates were physically removed from a section of the stream bed on the date of treatment. These areas were later sampled for invertebrates in comparison to adjacent undisturbed areas in order to measure the recolonization of the invertebrates.

The only invertebrate displaying a reduction in numbers at the treated sites was the caddisfly Philopotamidae. The chironomids of the family Orthocladiinae were reduced at only two of the four treated sites, but showed no significant change at the other sites. There were no significant changes in the numbers of caddisflies Hydropsychidae, stoneflies Plecoptera, blackflies Simuliidae, and oligochaetes Lumbriculidae. The stream mayflies of the families Heptagenidae and Leptophlebia as well as the craneflies Tipulidae actually increased in numbers following treatment. Except for increases in the stream mayflies Heptagenidae at one site, there was no difference in the numbers of invertebrates in the areas denuded of animals during treatment and the neighbouring undisturbed area.

A total of 183 surber samples have been collected at four sites in Wilmot Creek between May 1982 and November 1983. Forty more samples are proposed for May 1984. A further 32 drift samples were collected prior to, and during the lampricide treatment of the stream during October 1983.

B.4. Adaptive Environmental Assessment

This project covers involvement with the Great Lakes Fishery Commission (GLFC) through the Board of Technical Experts (BOTE) and the use of Adaptive Environmental Assessment (AEA) Workshops, and promotion of the use of modelling in planning and research at GLFRB. There were four activities undertaken in 1983:

(i) Invited to attend GLFC-sponsored workshop on lake trout research needs (CLAR-83).

(ii) Began work with co-BOTE members, Cooley (GLFRB) and J.Forney (Cornell) to assess the use so far of AEA by the GLFC.

(iii) Began work as biometrics advisor on the committee organizing a workshop for evaluating sea lamprey populations, using a modification of the AEA process.

(iv) Began work on Great Lakes Modelling Task Force to provide the Science Advisory Board of the IJC with advice on the role and use of modelling in Great Lakes planning and research.

B.5. Pink Salmon Project

An estimated 100 to 200 fish were present on Lake Ontario tributaries during September 1983 as compared to two fish during the previous generation. Most

of the occurrences were along the northwest shore with Wilmot and Bronte Creeks having the greatest number of sightings. Fish were also present in Hamilton Harbour, Bowmanville Creek, Ganaraska River and Shelter Valley Creek. The New York fisheries personnel have not yet reported fish in the eastern and southern Lake Ontario tributaries where several fish were reported during 1979.

Most of the fish were restricted to the lower sections of the streams. The high water temperatures (up to 19°C) during late September and the very heavy angling on the few fish present may prevent the regeneration of the fish in Lake Ontario.

Lake Erie eggs are viable with about 52 percent mortality prior to hatch in very poor conditions. Hatching occurred 46 days after fertilization (September 21) at the natural stream temperatures of Wilmot Creek. Therefore, Lakes Erie and Ontario eggs should hatch in early November. Yet undetermined is the time spent as larvae in the gravel.

OMNR and the N.Y. Department of the Environment reported very large runs of spawning fish in Lake Erie tributaries. The main run was in Youngs Creek, Port Ryerse, with an estimated 1,000 fish - double that of previous years. OMNR at Simcoe presume that the fish are now reproducing in Lake Erie and are not strays from Lake Huron. All the fish present in Lake Ontario during 1983 are presumed strays from this Lake Erie stock.

B.6. Production of Phytoplankton and Invertebrates in South Bay, Lake Huron

Estimates of mass sedimentation rate in the main basin vary from 39 to 51 g $m^{-2} yr^{-1}$ using 210Pb methodology. Sediment enrichment factors were 2 to 12

for cadmium, 5 to 7 for lead, 1.4 to 2.5 for mercury, and 1.8 for other metals (copper, nickel, zinc, chromium). Phosphorus loading rates apparently have increased only marginally in recent times.

Standing stocks of macrophytes varied from 0.0025 to 53.548 g m^{-2} dried weight; principal species of submerged macrophytes were Nitella sp., Chara sp., Potamogeton pectinatus, P. praelongus, P. angustifolius, Elodea canadensis and Myriophyllum sp.

Principal benthic macroinvertebrates on macrophytes were Dicrotendipes, Micropsectra, and Procladius spp. (Chironomidae); Polyentropus (Trichoptera); Caenis sp. (Ephemeroptera); immature Tubificidae and Hyallela azteca (Amphipoda).

Principal benthic macroinvertebrates were Peloscolex ferox (Tubificidae); Pontoporeia affinis (Amphipoda); Procladius, Dicrotendipes, and Phaenopsectra spp. (Chironomidae); Hydrobiidae (Gastropoda); Pisidium compressum (Sphaeriidae). Standing stocks varied from 42 n m^{-2} to 1656 n m^{-2}.

Work in 1983 and 1984 will focus on working up 14C production rates, analysis of P. affinis populations, description of macroinvertebrate communities. Plans for additional field work, if any, await OMNR decisions on the in-house research programs, facilities, and personnel.

B.7. Zooplankton and Larval Whitefish: Georgian Bay and Lake Huron.
In collaboration with the Lake Huron Fisheries Assessment Unit of the Ontario Ministry of Natural Resources, several inshore areas of Lake Huron were sampled for larval fish and zooplankton during the period late March to early June, 1983. Stokes Bay, Red Bay, Pike Bay, Howdenvale and Fishing Islands

were sampled weekly. This was the second years' work in a multi-year project to establish a trend-in-time data base useful for examining the relationship between whitefish year-class strength, known to be established by 0+ survival, and zooplankton abundance and timing.

Water samples were also taken for nutrient analyses, algae, and 'particles' (for Coulter Counter analysis). The Mary Wards shoal near Collingwood was examined on one occasion.

Although all zooplankton samples have been counted, data analysis probably should be delayed until several years of data on larval fish, zooplankton, and abiotic data are available. Future work should be based on data from the two very different environments represented by the Stokes Bay-Fishing Islands and the Meaford-Collingwood sections.

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